STUDIES ON THE MORPHOGENETIC, GONADOTROPIC AND LETHAL EFFECTS OF SOME BOTANICALS ON AN ECONOMICALLY IMPORTANT INSECT

DISSERTATION

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CERTIFICATE

This is to certify that the research work presented in the dissertation entitled "**Studies On The Morphogenetic, Gonadotropic And Lethal Effects Of Some Botanicals On An Economically Important Insect.**" by Ms. Priyanka Jacob is original and was carried under my supervision. I have permitted Ms. Priyanka Jacob to submit it to the Department of Zoology, Aligarh Muslim University, Aligarh in partial fulfillment for the award of the degree of Master of Philosophy in Zoology (Entomology).

Dr. (Mrs.) AYESHA QAMAR
(Supervisor)

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(Priyanka Jacob)

Introduction

INTRODUCTION

Man is perhaps the single most important agent, who has, from time to time, disturbed the 'balance of nature' and this has caused numerous pest problems and pest epidemics. The nature too, plays an important role in causing pest epidemics. Favorable conditions which reduce the natural mortality and bring the rapid development of the insect coupled with the conditions unfavorable to the natural enemies of that insect, often result in the rapid increase of its population leading to a sudden pest out-break. Once it is established that an insect is causing economic losses, it becomes necessary to control it.

Cereals like rice, wheat and maize constitute a major portion of the world's food produce. Ever since the advent of stabilized agriculture storage of the produce has remained an issue of utmost concern. Some 10,000 species of the more than 1 million species of insects are crop eating and of these approximately 700 species worldwide cause most of the insect damage to man's crop in the field and in storage.

Some insects prefer certain kinds of grains and not all insects eat the same part of the grain kernel. Storage insects can be divided into 3 group i.e. 1°, 2° and 3° pests. 1° pests can breakdown the hard seed coat of the undamaged grains. Some of these species lay their eggs inside the kernel and the growing larvae eat the inside of the kernel. Other species lay their eggs on the outside of the kernel. The hatched larvae eat their own way through the hard seed coat toward the very nutritious inside e.g. rice weevils, bean weevils, and lesser grain borers. 2° pests are not able to break through the hard undamaged seed coat. They follow the first attackers. These pests feed on the grain which has broken and cracked seed coats. 2° pests usually attack a wide range of commodities, e.g. flour beetles, saw toothed grain beetles, rusty gram beetles, Indian meal moth and rice moth *Corcyra cephalonica.* 3° pests feed on broken grains, grain

dust and powder left by the previous group e.g. grain weevil (*Cryptolestes pusillus*).

Most infestations of the small grains originate after they are placed in storage. Insects that breed in grain while it is in storage, and then live over between crops in the woodworks of bins, are responsible for much of this infestation. However, infestation in farm-stored grain may be initiated or supplemented by insects flying or crawling from other nearby sources, such as accumulation of waste grains or milled products.

Infestation of stored products by insects results in a variety of damage and economic loss including:

- Physical loss of commodity by direct consumption.
- Spoilage and loss of commodity quality due to physical and nutritional damage.
- Waste of effort taken in growing, handling, manufacturing and storing commodities which are destroyed by insect infestation.
- Encouragement of mould growth including of those fungi that produce mycotoxins.
- Contamination of commodities with insect bodies, waste products etc. some of which are toxic, repulsive or allergenic.
- Rejection by consumers of infested commodities and the resultant social and legal costs.
- Risk to health safety and the environment relating to use of pesticides and fumigants.

The origin of the insect pests of stored grain is not well known. Undoubtedly they formerly lived in the fields, some of them breeding in supplies of seed that escaped the attention of birds and animals, other feeding on the dried and decaying remains of plant or animal life, while still others bore into the roots, tubers, and stem of plants. The custom of storing seed adapted by man in early times provided an easy living for the insects

accidently brought in with these stores. Many of the insect pests of stored grain and milled cereals are of tropical or subtropical origin.

Stored-product insects can cause post harvest losses, estimated from 9% in developed countries to 20% or more in developing countries (Phillips and Throne, 2010). According to an estimate, the overall damage caused by stored-grain insect pests account for 10-40% worldwide annually. In India, food grain losses during storage at the farm level approximate 10% of the total production. In spite of improved storage structures and modern chemical and physical control techniques employed for the safe storage of stored grains, 70-90% of food grain is still stored for six months to a year at farmer's level in traditional storage structures.

According to World Bank Report (1999), post harvest losses in India amount to 12 to 16 million metric tons of food each year. The monthly value of these losses amounts to more than Rs 50,000 crores per year (Singh, 2010). In such a critical situation, protection of stored grains from insect infestation is quite essential and to achieve this goal, the use of several synthetic pesticides came into existence (Chaubey, 2001). The use of conventional pesticides such as organochlorines, organophosphates and carbamates, has resulted in multifarious hazard problems like toxicity to humans, pollution, bioaccumulation, poisoning and teratogenic effects of residues and the development of pesticide resistance. These pesticides and their metabolites that run–off treated lands generally enter nearby aquatic systems and scathe the aquatic fauna. Losses owing to fish kill alone are enormous because of the careless use of pesticides. Birds and mammals also suffer from exposure to pesticides. Deleterious effects include death from exposure to high doses, reduced survival, growth and reproduction from exposure to sub-lethal dosages and habitat reduction through elimination of food sources (Pimental *et al.*, 1980).

Currently, phosphine and methyl bromide have been the two common fumigants used for stored-product protection. But insect resistance to phosphine is a global issue now, and control failures have been reported in field situations in some countries (Taylor, 1989). Methyl bromide use is being phased out because of depletion of the ozone layer. Recently, other fumigants such as sulphuryl fluoride (Prabhakaran, 2006), carbonyl sulphide (Desmarchelier, 1994) have also been investigated to control insect pests. Therefore, there is an interest in finding alternative ways for stored products protection, especially within the scope of natural products that are known to be useful and non-toxic for human health and environment (Popovic *et al.*, 2006).

Essential oils are defined as any volatile oil(s) that have strong aromatic components and that give distinctive odour, flavour or scent to a plant. These are the by-products of plant metabolism and are commonly referred to as volatile plant secondary metabolites. Essential oils are found in glandular hairs or secretory cavities of plant-cell wall and are present as droplets of fluid in the leaves, stems, bark, flowers, roots and/or fruits in different plants. The aromatic characteristics of essential oils provide various functions for the plants including (i) attracting or repelling insects, (ii) protecting themselves from heat or cold; and (iii) utilizing chemical constituents in the oil as defense materials.

Most essential oils comprise of monoterpenes-compounds that contain 10 carbon atoms often arranged in a ring or in acyclic form, as well as sesquiterpenes which are hydrocarbons comprising of 15 carbon atoms. Higher terpenes may also be present as minor constituents. The most predominant groups are cyclic compounds with saturated or unsaturated hexacyclic or an aromatic system. Bicyclic (1,8-cineole) and acyclic (linalool, citronellal) examples also make the components of essential oils. Essential oils are usually obtained via. steam distillation of aromatic plants. Examples include 1,8-cineole, the major constituent of oils from rosemary

and eucalyptus; eugenol from clove oil; thymol from garden thyme; menthol from various species of mint; asarones from calamus; and carvacrol and linalool from many plant species. Eugenol from cloves, *Eugenia cryophyllus*; 1,8- cineole from *Eucalyptus globulus*; citronellal from lemon grass, *Cymbopogon nardus*; pulegone from *Mentha pulegium*, and thymol and carvacrol from *Thymus vulgaris* are among the most active constituents against insects (Lee *et al.*, 1997; Harwood *et al.*, 1990; Hummelbrunner and Isman, 2001).

A number of source plants have been traditionally used for protection of stored commodities, especially in the Mediterranean region and in Southern Asia, but interest in the oils was renewed with emerging demonstration of their fumigant and contact insecticidal activities to a wide range of pests in the 1990s (Isman, 2000). Essential oils are volatile and can act as repellent (Tripathi *et al.*, 2000), fumigants (Lee *et al.*, 2004), contact insecticides (Shaaya *et al.*, 1997), they also affect reproduction (Isik and Gorur, 2009).

The major components of the *Cedrus deodara* oil are beta-himachalene, alpha-himachalene, gamma himachalene, himachalol, allohimachalol, himadarol, isocentdarol and centdarol. The innerwood of the plant is aromatic and thus steam distillation is used for extraction to make essential oil. It has repellent and antifungal activity.

Camphor essential oil is extracted from the *Cinnamomum Camphora*. The volatile oil is obtained by steam distillation of the wood of the Camphor Tree followed by fractionation of the oil. The main chemical components are a-pinene, camphene, b-pinene, sabinene, phellandrene, limonene, 1,8-cineole, y-terpinene, p-cymene, terpinolene, furfural, camphor, linalool, bornyl acetate, terpinen-4-ol, caryophyllene, borneol, piperitone, geraniol, safrole, cinnamaldehyde, methyl cinnamate and eugenol. Camphor is used

in many commercial ointments, deodorants, disinfectants, paint solvents and soaps. It has repellent and insecticidal activity.

The *Eucalyptus globulus* oil is a complex mixture of a variety of monoterpenes and sesquiterpenes, and aromatic phenols, oxides, ethers, alcohols, esters, aldehydes and ketones; however, the exact composition and proportion of which varies with species (Brooker and Kleinig, 2006). Eucalyptus oil is extracted from the fresh or partially dried leaves and young twigs and extracted by steam distillation. The oil possesses a wide spectrum of biological activity including anti-microbial, fungicidal, insecticidal/insect repellent, herbicidal, acaricidal and nematicidal (Batish *et al.*, 2008).

Peppermint oil extracted by steam distillation from the leaves of *Mentha piperita*. It contains menthol, menthone and menthyl esters. Menthone, present in high concentration in peppermint oil, is reported to act as a natural pesticide (Robert, 2001).

Constituents of *Citrus aurantium* (bitter orange) include flavonone glycosides and flavone aglycones, coumarins, psoralens, polymethoxyflavones, waxes, aldehydes, amines, and monoterpenes (Boelens and Chouchi *et al.*, 1996). This oil is either produced by cold press or steam distilling the peel. It is used as a natural insecticide against several pests.

Cymbopogon citratus (lemongrass) is extracted from the fresh or partly dried leaves by steam distillation. The main chemical components of lemongrass oil are myrcene, citronellal, geranyl acetate, nerol, geraniol, neral and traces of limonene and citral. It has repellent and insecticidal activity.

The present investigation was conducted on the rice moth, *Corcyra cephalonica* (Stainton) (Family Pyralidae, Subfamily gallerinae) which is a serious lepidopteran pest of stored cereals such as wheat, rice, sorghum, maize, millet etc. in tropical and subtropical region of the world (Krishna, 1930 and Russel *et al.*, 1980). *Corcyra cephalonica* has a wingspan of 1.7 cm (males) to 1.9 cm (females). The wings are uniformly dark grey, sometimes streaked with darker lines along the veins. The head is snout like in females while blunter in males. It is an external feeder. The larva is initially creamy white and gradually darkens to a dirty white with a reddish brown head capsule. After completing development through five instars, it weaves a cocoon incorporating food grains, debris and other materials. The pupa is leathery brown and measures about 8 mm.

The female reproductive system of *Corcyra cephalonica* consists of a pair of ovaries. Each ovary is composed of four ovarioles. Distal end of each ovariole is called germarium which is followed by the vitellarium. Vitellarium includes major portion of the ovariole in which a series of immature eggs become progressively larger. Each ovary opens into lateral oviduct. The two lateral oviducts unite in a single median common oviduct. Typically, the common oviduct is heavily invested with muscles and the lateral oviduct less so. The distal end of common oviduct is called gonopore. Genital chamber modifies to form a capacious bursa copulatrix which acts as a receptable for male intromittent organ. A pair of accessory gland is present in the reproductive system of *Corcyra cephalonica.*

There are on an average of 240-275 eggs in various stage of development in the ovaries of female adults of *Corcyra cephalonica.* Eggs are pearly white ellipsoids with a rough, irregularly sculpted surface and a small nipple at one end. The eggs of the factitious host insect, *Corcyra cephalonica* are used for production of several natural enemies in many countries across the world e.g. *Trichogramma* species which are used widely for the

biological control of lepidopterous pests on various crops in more than 30 countries (Jalali *et al.*, 2007).

In perspective of the damage caused by *Corcyra cephalonica,* the efficacy of six essential oils i.e. Cedarwood (*Cedrus deodara*), Camphor (*Cinnamomum Camphora*), Eucalyptus *(Eucalyptus globules)*, Peppermint (*Mentha piperita*), Lemongrass (*Cymbopogon citrates*) and Bitter orange (*Citrus aurantium*) were assayed for their lethal, morphogenetic and gonadotropic effects via contact and fumigation application.

Review of Literature

REVIEW OF LITERATURE

Overuse of synthetic pesticides creates environmental problems and health hazards which is the main matter of concern for scientists and public in recent years. Excellent alternative to synthetic pesticides are natural products, as a means to reduce negative impacts to human health and environment. Among the botanicals, essential oils are a major category that began to develop with the research in the 1980s. The essential oils have the complex mixture of volatile organic compounds, reported to be biologically active and are endowed with insecticidal, antimicrobial and bio-regulatory properties. Besides this, they have many industrial applications: perfumery, cosmetics, detergents, pharmacology and food production products. Steam distillation is the most commonly used method for producing essential oils on a commercial basis. Extraction by means of liquid carbon dioxide under low temperature and high pressure produces a more natural organoleptic profile but is much more expensive (Moyler, 1998). Essential oils are volatile and therefore need to be stored in airtight containers in the dark in order to prevent compositional changes. Many plant essential oils show a broad spectrum of activities like insecticidal, oviposition deterrent and repellent against several insect pests. Extensive work on review of essential oil has been done by Koul *et al.,* (2008).

Insecticidal activity of essential oils

Several essential oils such as cedarwood, eucalyptus, camphor, peppermint, lemongrass and bitter orange oil etc. have been reported to exhibit insecticidal activity against insect pests. Cedarwood oil shows insecticidal activity to a wide variety of insect pests. Chromatographic fractions of *Cedrus deodara* were bio-assayed against the pulse beetle (*Callosobruchus. analis*) and the housefly (*Musca domestica*). These fractions contain himachalol and β-himachalene, these two sesquiterpenes caused 97.5% mortality at 0.56 µmol/insect against the pulse beetle (Singh and Agarwal, 1987). The degree of toxicity of essential oils to different

insect pests differs considerably. Raguraman and Singh, (1997) found that cedarwood oil exihibited potential at 3, 2 and 1% concentrations showing corrected inhibition (knock-down) of 100, 100 and 96% respectively of *Callosobruchus chinensis.* Apart from these insects essential oils were found to be toxic to ticks also. Geer Panella *et al.,* (1997) reported on the biocidal activity of essential oils against *Ixodes scapularis* by using the disposable pipette assay. Of the 13 plant extracts evaluated, Alaska yellow cedar was most effective against nymphal ticks (0.15% wt:vol) with Eastern red cedar showing the greatest activity against larval ticks (0.001% wt:vol). Many of the species belonging to genus Cedrus have been previously reported for their various biological activities (Shinde *et al.*, 1999). The biocidal activity of three distilled essential oils–incense cedar, *Calocedrus decurrens*, post–orford cedar, *Chamaecyparis lawsoniana* and Western juniper, *Juniperus accidentalis* were evaluated against *Aedes aegypti* and *Xenopsylla cheopis* and nymphal *Ixodes scapularis*. Although all three oils exhibited some level of biocidal activity on the basis of LC_{50} and LC_{90} values, incense cedar was the most toxic to all three arthropod test species (Dolan *et al.*, 2007).

Shaaya *et al.,* (1997) reported the outstanding toxicity of eucalyptus oil showed against *Sitophilus oryzae* and *Rhyzopertha domonica*. Tuni and Shinkaya, (1998) recorded lethal effects of *Eucalyptus camaldulensis* oil against cotton aphid. Lee *et al.,* (2001) who reported that eucalyptus oil showed fumigant activity against *Sitophilus oryzae.* Eucalyptus oil obtained from different species of eucalyptus plant has been reported as potential toxicant against stored product insects. Lee *et al.,* (2004) found that essential oils of *Eucalyptus nicholii*, *Eucalyptus codonocarpa*, *Callistemon sieberi*, *Melaleuca fulgens*, *Eucalyptus blakelyi* and *Melaleuca armillaris* had potent fumigant toxicity against *Sitophilus oryzae*. Moreover, Regnault-Roger *et al.,* (2004) showed that *Eucalyptus globulus* essential oil had ovicidal and larvicidal activity against *Acanthoscelides obtectus*. Clemente *et al.,* (2006) tested cineole activity against an agricultural pest, the fruit fly

Ceratitis capitata. Negahban and Moharramipour, (2007) found that the essential oils of *Eucalyptus intertexta*, *Eucalyptus sergentii* and *Eucalyptus camaldulensis* caused high mortality rate in *Callosobruchus maculatus* compared with *Sitophilus oryzae*. In another study, the activity of *Ashbya gossypii* at the four concentrations was assayed. At 12000 and 18000 ppm mortality reached values to 100% in the first two hours. The other two concentrations assayed (3000 and 6000 ppm) caused average mortality values of 55-60% in the first four and 84.86% in the second hours (Mareggiani *et al.*, 2008). Essential oils obtained from *Gomortega keule*, *Laurelia sempervirens*, *Origanum* vulgare, *Eucalyptus globulus* and *Thymus vulgaris* were analyzed and evaluated for their toxicity against adults of *Sitophius zeamis* and *Acanthoscelides obtectus*. Of the 5 plants tested, the essential oil of *Tribolium vulgaris* and *Eucalyptus globulus* were the most toxic against *Sitophilus zeamis* adults. Mortality was around 55% for *Sitophilus zeamis* (Magalist *et al.*, 2008). Eucalyptus oil showed insecticidal toxicity against eggs, larvae and adults of *Tribolium castanaeum* (Nattudurai *et al.*, 2010). In eucalyptus oil the major component is 1,8 cineole and this compound is responsible for the oils biological activity (Maciel *et al.*, 2010). Essential oils of *Melaleuca alternifolia*, *Cinnamomum zeylanicum*, *Syzygium aromaticum*, *Cymbopogon flexuosus*, *Thymus vulgaris*, *Eucalyptus globules* and *Simmondsia chinensis* were tested against *Callosobruchus maculatus* and *Sitophilus oryzae* adults. *Callosobruchus maculatus* were more sensitive than *Sitophilus oryzae* to the essential oils of *Syzygium aromaticum* and *Eucalyptus globulus* whereas the LC_{95} values were 1.032 and 3.66 µl/50 ml air respectively (Ahmed and Salam, 2010). According to Sivakumar *et al.* (2010), the essential oils of eucalyptus, citronella, rosemary, cardamom and geranium attained LD_{50} for *Callosobruchus maculatus* respectively at 11.66, 16.25, 21.35, 22.07 and 25.11 µl/l-1 of air. The efficacy of the oils followed in the order: eucalyptus > citronella > rosemary > cardamom > geranium.

The biological activity of camphor against *Sitophilus granaries*, *Sitophilus zeamis*, *Tribolium castanaeum* and *Prostephanus truncates*, were investigated by Obeng-Ofori *et al.*, (1998). Rozman *et al.*, (2006) found that camphor acted as fumigant caused 100% mortality to *Cryptolestes pusillus* at a dose of 1µl/7.2 ml vol. Insecticidal activity of camphor was also tested against *Sitophilus oryzae* and *Bruchus rugimanus* by Liu *et al.*, (2006). Al-Jabr, (2006) showed 100% mortality of *Oryzaephilus surinamensis* was obtained with *Cinnamomum camphora.*

According to Achremowicz, (1995) essential oils derived from lemon, orange and thyme result in 50% aphid mortality over 48 hours. Morawej and Abbar, (2008) studied the effect of *Citrus pardesi*, *Citrus aurantium*, *Citrus limonium* and *Citrus sinensis* oil against *Callosobruchus maculates.* Peel oils of lemon, grapefruit and navel orange were tested for insecticidal activities against larvae and adults of *Culex pipiens* and *Musca domestica*. The orange peel oil was the least effective against larvae and adults of both species (Shalaby *et al.*, 1998). The essential oil of *Citrus sinensis* at the highest dose of 0.75g/250g of haricot bean gave 67.4% mortality after 96 hours of exposure to *Zabrotes subfasciatus* (Zewde and Jembere, 2010).

Lemongrass oil is of great use and value in the agriculture sector, especially for the protection of stored agricultural products, such as the staple food crop, maize. Essential oils of *Cymbopogon citratus* (Lemongrass) and *Murraya koenigii* (Curry leaf) were tested for its toxicity and against *Callosobruchus maculatus* in stored cowpea. Lemongrass oil at a concentration of 0.15 g/l caused 100% mortality (Paranagama, 2002). A dosage of 2.75 mg cm^{-2} of lemongrass oil produced 90 and 95% mortality after 24 and 48 hrs (Masamba *et al.*, 2003).

Peppermint oil offered the highest toxicity to adults and larvae of the black carpet beetle at LD_{50} level (Bakr *et al.*, 2010). The toxicity of essential oils of *Mentha piperita* and *Mentha spicata* at concentrations of 5%, 10% and 20% were evaluated against adults of *Amblyomma hebraeum* (Mkolo *et al.*,

2011). Tah *et al.*, (2011) evaluated the essential oils of *Mentha piperita* and *Eucalyptus platyphylla* at different concentrations on adults of *Ahasverus advena*, *Carpophilus hemipterus* and *Tribolium castanaeum*. *Mentha piperita* caused the highest mortality rates ranging from 86.82 to 98.61% at the concentration value of 33.3µl/l.

Reproductive effect

Several essential oils or their components have been assayed for ovipositional deterrent activity against a number of insect pests. The ability of essential oils and monoterpenoids to reduce fecundity in *Acanthoscelides obtectus* has been already reported by Regnault-Roger and Hamroni, (1995). A significant reduction of egg deposition was found in Yougoslavian and Russian *Acorus calamus* oil at doses of 5 and 10 µl, however, in lower doses oviposition was not affected (Rahman and Schmidt., 1999). Essential oils from *Tagetes minuta*, *Hyptis suaveolens*, *Ocimum canum* and *Ocimum basilicum* have caused complete inhibition in *Callosobruchus chinensis* (Keita *et al.*, 2001). Papachristos and Stamopoulos, (2002) showed that essential oils tested (*Morelia Viridis*, *Eucalyptus globulus*, *Mutisia microphylla*, *Rosmarinus officinalis* and *Lavandula hybrida*) against *Acanthoscelides obtectus* reduced the number of egg laid, whereas fecundity was adversely influenced at two levels. The first was the inhibition of oogenesis and the second, the increased egg retention in the lateral oviducts. In *Tribolium castaneum*, the *Curcuma longa* oil reduced oviposition and egg hatchability by 72% and 80% respectively at the concentration of 5.2 mg/cm^2 (Tripathi *et al.*, 2002). Toxicity, repellency and anti-reproductive effect of essential oils from basil and sage dependent on their concentrations and time of insect exposure (Popovic *et al.*, 2006). Ngamo *et al.*, (2007) have reported similar results against *Sitophilus oryzae* when applied with essential oils alone or in balanced combinations. The effect of *Aegle marmelos* on oviposition of *Callosobruchus chinensis* was studied. Oviposition deterrent activity of the

oil for *Callosobruchus chinensis* enhanced with dose. The oviposition was reduced to 56.25% at 100 µl oil dose (Kumar *et al.*, 2008). The essential oils from seven common spices i.e. *Anethum graveolens*, *Cuminum cyminum*, *Illicium verum*, *Myristica fragrans*, *Nigella sativa*, *Piper nigrum* and *Trachyspermum ammi* were isolated and their insecticidal, oviposition, egg hatching and developmental inhibitory activities were determined against pulse beetle, *Callosobruchus chinensis*. The essential oils reduced the oviposition potential (Chaubey, 2008). The highest oviposition deterrency of *Callosobruchus maculates* when exposed *to Thymus vulgaris* were observed at highest concentration of 1500 ppm (Dezfouli *et al.*, 2010). Apple mint and pennyroyal essential oils at the highest applied concentration (1.0%) showed a highly significant effect in reducing egg laying of *Callosobruchus maculates* on the cowpea seeds to 10.2 and 12.4 eggs/females, respectively (Aziz and Abbass, 2010). Essential oils of 3 aromatic plants i.e. *Melaleuca quinquenercia*, *Citrus aurantifolia* and *Ageratum conyzoides* significantly reduce the number of eggs laid per female compared to that obtained in the control. This reduction was observed already with the lowest concentration (6.7µl/l), with a reduction ratio of the egg laying from at least 90% compared to the control. These essential oils vapours could involve ovarian changes similar to those caused by chemosterilisants by blocking female eggs laying (Aboua, 2010). Singh *et al.,* (2011) demonstrated that out of eight compounds studied, viz., thymol, 1,8-cineole, linalool, a terpineol, trans-anethole, carvacrol, eugenol, and methyl eugenol, thymol showed the strongest reduction in oviposition preference and 100% reduction in egg laying was recorded at 3 mg ml^{-1} concentration. There was no significant inhibition of egg hatching. There was an overall 0.3–17.3% reduction in hatching of these eggs, which was comparable to controls (0.2 – 12.6%). Recently Sharma *et al.*, (2011) studied the effect of *Origanum majorana* oil on oviposition of *Callosobruchus chinensis* in the treated cowpea samples. At 5 ppm concentration of oil, the number of eggs laid decreased.

Repellent activity

A large number of Essential oils extracted from different families have been shown to have high repellency against arthropod species. *Cymbopogon* plants have been traditionally used to repel mosquitoes in jungle regions such as the Bolivian Amazon (Moore *et al.*, 2007). This genus produces the most used natural repellents in the world (Trongtokit *et al.*, 2005). *Cymbopogon winterianus* oil, mixed with 5% vanillin, gave 100% protection for 6 hrs against *Aedes aegypti*, *Culex quinquefasciatus* and *Anopheles dirus*, results compared to those observed with 25% DEET (N,N-diethyl-3-methylbenzanmide) (Tawatsin *et al.*, 2001). Many extracts and essential oils isolated from these plants have been tested against different kinds of arthropods. *Cymbopogon excavatus* gave 100% repellency for 2 hrs, when it was evaluated in the laboratory against *Anopheles arabiensis* and its repellency decreased to 59.3% after 4 hrs (Govere *et al.*, 2000). In contrast, *Cymbopogon nardus* oil evaluated against *Cydia pomonella* (Lepidoptera) (Landolt *et al.*, 1999), as well as *Cymbopogon nardus* and *Cymbopogon flexuosus* against *Lasioderma sericorne* (cigarette beetle), were inactive. The oil of *Cymbopogon martinii martinii* provided 100% repellency for 12 hrs against *Anopheles* mosquitoes in a field test which was carried out by using pairs of volunteers who sat together, one of whom was treated with the oil while the other was not (Ansari and Razdan, 1994).

Repellent properties of essential oils and extracts from genus *Eucalyptus* are also well documented. These presented high repellency against *Ixodes ricinus*, *Aedes albopictus*, *Mansonia* and *Pediculus humanus capitis* (Toloza *et al.*, 2008; Jaenson *et al.*, 2006; Yang and Ma, 2005 and Hadis *et al.*, 2003); low activity to *A. aegypti* and larvae of *Cydia pomonella* (Gillij *et al.*, 2008; Trongtokit *et al.*, 2005 and Landolt *et al.*, 1999), and no effect on *Lasioderma. sericorne* (cigarette beetle) (Hori, 2003). Repellents based on eucalyptus oils have been formulated and evaluated against *Leptoconops* biting midges (Carroll and Loye, 2006).

Oils extracted from the *Ocimum* have been traditionally used as repellents (Padilha de Paula *et al.*, 2003). *Ocimum americanum* volatile oil was shown to repel *Anopheles aegypti*, *Anopheles dirus* and *Culex quinquefasciatus*, under cage conditions, for up to 8 hrs (Tawatsin *et al.*, 2001); an ethanolic solution of *Ocimum selloi* oil (10% v/v) seemed to be very effective in repelling *Anopheles braziliensis* (Padilha de Paula *et al.*, 2003); and liquid paraffin solutions of *Ocimum gratissimum* L. and *Ocimum basilicum* L. oils exhibited a high bite-protection (Gbolade *et al.*, 2000).

A number of plants and their products have been traditionally used for protection of stored commodities, especially in the Mediterranean region and in Southern Asia, but interest in the oils was renewed with emerging demonstrations of their contact insecticidal and fumigant activities to a wide range of pests in the 1990's.

Contact Bioassays

There are numerous reports concerning the evaluation of different essential oils against several stored grain pests by contact application. The essential oil of *Citrus sinensis* showed contact toxicity against *Zabrotes subfasciatus* (Zewde, 2010). The LC_{50} of *Citrus reticulata* oil was found 22.879 µl and 18.733 µl at 24 and 48 hrs exposure against adult of *Sitophilus oryzae*, respectively (Mishra *et al.*, 2011). The contact activity of essential oil extracted from *Ailanthus altissimia* bark was evaluated for against four major stored grain insects i.e. *Sitophilus oryzae*, *Oryzaephilus surinamensis*, *Tribolium castanaeum* and *Liposcelis pecta*. This oil showed the stronger contact toxicity against *Sitophilus oryzae* adults with the corrected percent mortality 76.55 after 72 hrs treatment and weak contact toxicity against *Oryzaephilus surinamensis*, *Tribolium castanaeum* and *Liposcelis pecta* (Lu and Wu, 2010). Recently Liu *et al.*, (2011) mentioned that contact activity of *Artemisia argyi* oil against *Oryzaephilus surinamensis* in grains progressively increased with increased dose exposure.

Fumigant bioassays

Research studies on plant essential oils and their constituents as fumigants i.e., compounds acting on target insects in the vapour or gaseous phase, against stored-product insects have been reviewed by Rajendran and Sriranjini, (2008).

Essential oils being volatile are more use insect fumigants. Several studies have been undertaken in the past to explore the potential of essential oils and their constituents as insect fumigants. *Mentha citrata* oil containing linalool and lanalyl acetate significantly exhibited fumigant toxicity against rice weevil, *Sitophilus oryzae* (Singh *et al.*, 1989). Toxicity of five essential oils viz. cardamom, cinnamon, clove, eucalyptus and neem oils were investigated against the cowpea weevil, *Callosobruchus maculates* (Fab.) adults, through fumigation bioassay. The efficacy in respect of the toxicity followed in the order: clove > cinnamon > cardamom > neem > eucalyptus after 24 hrs after treatment, and clove > cinnamon > cardamom > eucalyptus > neem after 48 hrs treatments (Mahfuz & Khalequzzaman, 2007). Chemical composition and fumigant toxicity of essential oil from *Perovskia abrotanoides* against *Sitophilus oryzae* and *Tribolium castanaeum* was determined. The predominant components in the oil were camphor (28.38%) and 1, 8-cineole (23.18%). Fumigant toxicity was tested against 1 to 7 days-old adults of the insects. The mortality increased with concentrations of 32, 161, 322, 483 and 645 µl/l air and with exposure time from 2 to 15 hrs. The oil at 322 µl/l air caused 100% mortality of *Sitophilus oryzae* and *Tribolium castanaeum* within 13 and 7 hrs exposure, respectively (Arabi *et al.*, 2008). The essential oil of *Armoracia rusticana* was shown to possess fumigant bioactivity against all stages of *Plodia interpunctella* and adults of *Sitophilus zeamis* (Chen *et al.*, 2011).

Corcyra cephalonica is a serious lepidopteran pest of stored cereals such as wheat, rice, sorghum, maize, millet etc. in tropical and subtropical region of the world (Krishna, 1930 and Russel, 1980). Toxicity evaluation of

different plant extracts were done by various scientists on *Corcyra cephalonica*. Shukla *et al.*, 2001 tested *Cymobopogon flexuosus* oil *against Corcyra cephalonica, Sitophilus oryzae, Rhyzopertha dominica, Tribolium granarium* and *Ephestia cautella*. Total mortality was obtained after 7 hrs for *Rhyzopertha dominica* and *Sitophilus Oryzae*, after 6 hrs for *Tribolium granarium* and after 8 hrs for *Corcyra Cephalonica* and *Ephestia cautella* (Senguttuvan *et al.*, 1995) did experiment in which kernels and pods of groundnuts were treated with Nochi (*Vitex nigunto* L.) leaf powder, neem (*Azadirachta indica* L.) leaf powder, neem kernel powder, neem cake powder and oil of neem, castor (*Ricinus communis* L.), sesame (*Sesamum indicum* L.) and groundnuts. It was found that with all these plant powders and oils tested, losses from *Corcyra cephalonica* were less than in untreated controls.

Adults of *Corcyra cephalonica* when exposed to volatiles of leaves of tulsi or eucalyptus reduced egg yield in females (Maini *et al.*, 1993). Pathak and Krishna, (1991) evaluated the effect of neem oil volatiles by confining the adults and larvae of *Corcyra cephalonica* in a chamber containing neem oil. They recorded a marked decline in the reproductive potential and egg hatchability. Earlier Pathak *et al.*, (1985) demonstrated that the reproductive potential (expressed in terms of egg yield and egg viability) of the rice moth, *Corcyra cephalonica* was significantly lowered when the pest is exposed to vapours of neem oil emanating from 160 µl of the oil.

Materials and Methods

MATERIALS AND METHODS

(I). INSECT CULTURE

***Corcyra cephalonica*:** The eggs of *Corcyra cephalonica* were obtained from Tropical Forest Research Institute, Jabalpur. These eggs were kept in glass rearing jars measuring 20×15 cm containing food.

Preparation of food: Coarsely ground maize was taken and sterilized at 100°C for 3 hrs in dry air oven then it was kept for few hours for getting it at room temperature. In 5 kg food, 1 gm of streptomycin powder (as antibiotic) was mixed. In 1 litre of glass jars, 300 grams of food was placed in each jar and about 300 eggs of *Corcyra cephalonica* were introduced. These jars were placed in REMI's Environmental chamber maintained at 27±2°C temperature and 70-80% relative humidity. The jars at the top were covered with a piece of muslin cloth tightly fixed by means of rubber band to stop the exit of an insect. When the adults emerged these were transferred to jars containing honey soaked solution in cotton for oviposition. Eggs were collected from these jars then transferred to fresh rearing jars containing coarsely ground maize. Overcrowding was avoided for proper growth of an insect.

(II). SAMPLING OF EXPERIMENTAL INSECTS

In the present work 3rd instars of *Corcyra cephalonica* larvae were sorted out and maintained in separate jars. They moulted to 4th instar larvae within 7-8 days. The newly moulted larvae were then treated with different concentrations of essential oils.

(III). CHEMICALS USED

1. *Cedrus deodara.*

The oil is yellow-brown to reddish brown, slightly viscous oil with an odour that is slightly dirty, somewhat crude and woody. The major components of the oil were β-himachalene (38.3%), α-himachalene (17.1%) and γ-himachalene (12.6%). Empirical formula of β-himachalene is $C_{15}H_{24}$.

2. *Cinnamomum camphora*

Camphor is a waxy, white or transparent solid with a strong, aromatic odor. It is a terpenoid with the chemical formula $C_{10}H_{16}O$. Chemical structure is 1, 7, 7-Trimethylbicyclo [2.2.1] heptan-2-one.

3. *Eucalyptus globulus*

Eucalyptus has a clear, sharp, fresh and very distinctive smell, is pale yellow in color and watery in viscosity. Chemical constituents are monoterpenes; sesquiterpenes: sesquiterpenols; terpene oxides: 1, 8 cineole (70-75 percent). Chemical structure of 1, 8-cineole is 1, 3, 3-trimethyl- 2-oxabicyclo [2, 2, 2] octane and empirical formula is $C_{10}H_{18}0$.

4. *Mentha piperita*

Peppermint oil has a fresh, sharp, menthol smell, is clear to pale yellow in color and watery in viscosity. Main components are menthone (12.70%), menthone (37.40%) and methyl acetate. Chemical name of menthol is (1*R*, 2*S*, 5*R*)-2-isopropyl-5-methylcyclohexanol and empirical formula is $C_{10}H_{20}O$.

5. *Cymbopogon citratus*

Lemongrass oil has a lemony, sweet smell and is dark yellow to amber and reddish in color, with a watery viscosity. The main chemical

components of lemongrass oil are 65-85% citral and active ingredients like myrcene, citronella, citronellol and geraniol. Chemical name of citral is 3, 7-dimethyl-2, 6-octadienal and emperical formula is $C_{10}H_{16}O$.

6. *Citrus aurantium*

Limonene, limonin bitter and non-bitter flavanoids, furanocoumarins, flavanoid glycosides, terpeniol, naringi, hesperidin, pectin, carotenoids, isohesperidin, Vitamin A, Vitamins B_1 and Vitamin C. Chemical name of limonene is 1-methyl-4-(1-methylethenyl)-cyclohexene and empirical formula is $C_{10}H_{16}$.

(IV). PREPERATION OF DIFFERENT CONCENTRATIONS OF ESSENTIAL OILS USED

For contact toxicity six concentrations of essential oils viz., 1.00%, 1.25%, 1.50%, 1.75%, 2.00%, 2.25% were prepared from 1% stock solution of different essential oils by serial dilution in acetone.

For fumigation toxicity six concentrations of essential oils viz., 200, 250, 300, 350, 400 and 450 $\mu l L^{-1}$ air were prepared. To make concentrations for fumigant toxicity the following formula was used:

Quantity of essential oil in µl/volume of container in ml × 1000.

(V). BIOASSAYS

Contact Application: Aliquots of 1 ml of the dilutions were applied on the surface of petridish of 5 cm dia. and allowed to evaporate for 5 mins (Fig. 2). For each concentration ten 4^{th} instar larvae were taken. Observations on larval mortality were made at an interval of 24 hrs. Parallel controls in acetone of the corresponding instars were also maintained for comparison.

Fumigant Application: Fumigant activity of the different essential oils was carried out against *Corcyra cephalonica* larvae with 10 insects exposed in 100 ml flask sealed with a stopper. Different concentrations of the essential oils were evenly applied to a Whatman No.1 filter paper strip of 2 cm diameter which was dried in air for 3 mins and then fixed on the stopper by cello tape (Fig. 2) Each concentrations and control was replicated 5 times.

(VI). METHODS FOR ESTIMATING MORTALITY AND FECUNDITY

After applying each dose of different essential oils in contact and fumigant toxicity larval mortality after 24 and 48 hrs was recorded. Parallel controls in acetone of the corresponding instars were also maintained for comparison. The female adults which were emerged after different dose treatment were paired with treated males of the corresponding age. Each pair was maintained in controlled condition in separate rearing jars also provided with standard food i.e. honey solution soaked cotton seeds. Daily fecundity of each treated pair as well as control was recorded. Females were also dissected out within 24 hrs of emergence to expose their reproductive system.

(VII). STATISTICAL ANALYSIS

The data obtained was statistically analyzed by the application of following methods and formulae.

Mean: It is obtained by summing up all the observations and dividing it by the total number of observations.

Mean ($\bar{X}$) = Mean ($\overline{X}$) = $\left(\frac{\Sigma X}{N}\right)$

where, X = sum of the observations,

N = number of observations

Standard deviation: It is used as a measure of dispersion and defined as "Root mean square deviation from mean".

$$\text{Standard deviation (SD)} = \sqrt{\frac{\Sigma\left(X-\overline{X}\right)^2}{N}}$$

where, X = value of variables

$\overline{X}$ = arithmetic mean

N = number of observations

Standard Error: It is the ratio of standard deviation of the sample divided by the square root of the total number of observations.

$$\text{Standard error (SE)} = \frac{SD}{\sqrt{N}}$$

where, SD = standard deviation

N = number of observations

Regression: The tendency to remain towards central position is called regression. In order to draw a relationship, observations of two variables are plotted in the form of dots in a scatter diagram. A straight line is drawn which will approach as close as possible to all these points in the graph. The existence of relationship between the independent variable X and the dependent variable Y can be expressed in a mathematical form known as the regression equation.

Regression equation of X on Y:

$X = a + b.y$

Regression equation of Y on X:

$Y = a + b.x$

where, x = value of variable

y = value of variable

a = constant

b = constant

Test of Significance: For test of significance the following formula was applied.

$$t = \sqrt{\frac{M_1 - M_2}{\frac{SD_1}{n_1} + \frac{SD_2}{n_2}}}$$

where, t = significant value

M_1 = mean value of first set of observations

M_2 = mean value of second set of observations

SD_1 = SD of first set of observations

SD_2 = SD of second set of observation

n_1 = Number of observations of first set

n_2 = Number of observations of second set

The calculated 't' value was compared with the tabulated 't' value at 1% level. If the former value is higher than the later value, the data is significant otherwise insignificant. The tabulated value of 't' at 1% level is 4.541.

Probit analysis:

This is done by testing the response of an organism under various concentrations and then comparing the concentrations at which one encounters a response. The response is always binomial (e.g death/no death) and the relationship between the response and the various concentrations is always sigmoid. Most common outcome of a dose-response experiment in which probit analysis is used is the LC_{50} and LC_{90}. **All statistical were performed by using MS-excel and SPSS (17.0 version).**

Results

RESULTS

Normal biology of *Corcyra cephalonica*

Number of eggs laid by an adult female ranged from 240-275. Freshly laid eggs were glistening, pearly white in colour with irregularly sculptured surface having small uneven areas demarcated on the surface. Eggs are pear shaped and gently rounded at one end and pointed at the pedicel end with brownish tinge (Figure 1a). Egg duration ranged from 4-7 days at 27± 2°C and 70% humidity.

There are six larval instars larvae in the life cycle of *Corcyra cephalonica* (Figure 2b). The first stage larva is creamy white in colour and of uniform thickness. It measure about 3 mm in length. The head capsule is yellowish white with a brownish margin. On emergence from the egg the 1st instar larvae are active, and start feeding on crushed grains. The instar lasts from 4-6 days. After the first moult the general appearance of the larva does not undergo much change. The larva now measures approximately 4 mm in length and this instar lasts for 5-6 days. Third instar larvae are approximately 5 mm in length. They molted within 3-5 days. Fourth instar larvae measures approximate 9 mm in length and moult within 3-5 days to fifith instar. Length of the fifth instar is approximately 11 mm. The general colour is dirty white. Most of the larvae moult in 6-7 days. Size of the last instar i.e. sixth stage measures up to 13 mm in length. This stage duration range between 7-9 days. All stages of larval instars feed in crushed grain produce a lot of frass and remain hidden in them. Infested grains are spun together in a tight web (Fig. 1c) Mature 6^{th} instar larvae spin a silken web. The white silken structure remains covered with small and large food grains, debris, excrement etc. After the cocoon is spun, the larvae become inactive and shrink in size achieving prepupal stage. The prepupal condition lasts for a day or two at the most.

The pupa is leathery brown in colour and measures about 7.5-8.5 mm in length (Fig. 1d). Adults emerge out from pupa and last up to 9-12 days.

Freshly emerged adults have crumpled wings (Fig. 1e) which become fully stretched in 12-24 hrs (Figure 6). The colour of the adult moth is grey and wingspan of the adult male and female measures about 1.1 cm and 1.5 cm respectively (Fig. 1f). The male and female can be easily distinguished on the basis of their proboscis. In male the proboscis is blunt while in female it is snout shaped. The mating between male and female occurs in 24 hrs of emergence which is followed by the egg laying.

(I). Contact bioassay of essential oils

(A). *Corcyra cephalonica* when exposed to individual essential oils through contact application

(a). Insecticidal activity

(i). Insecticidal activity of cedarwood oil against *Corcyra cephalonica*

The mean larval mortality following the application of different concentrations of cedarwood oil (1%, 1.25%, 1.5%, 1.75%, 2% and 2.25%) on 4th instar larvae of *Corcyra cephalonica* along with control (acetone) is presented in Table 1. Mortality was high within 24 hrs as compared to the mortality in next 24 hrs. Dead larvae shows darkened cuticle at all concentrations of cedarwood oil, however, some larvae became morbid, exhibiting very little movement in the first 24 hrs and eventually died following continued exposure of oil (Fig. 3). The larvae of control group, which were exposed to acetone only, exhibited negligible mortality. The regression between concentration strength and 4th instar larval mortality yielded a positive linear correlation (Y= 0.6537x-0.409, R^2= 0.9615) (Fig. 36). The lowest concentration (1%) of cedarwood oil produced only 28% total larval mortality which is approximately one fourth of the mortality obtained at 2% and 2.25% concentrations after 48 hrs of exposure. The

value of confidence limit ranged from 01.719-03.080 with the significant t value at 2% and 2.25% (Table 2).

(ii). Insecticidal activity of camphor oil against *Corcyra cephalonica*

The larvicidal activity of camphor oil was propotional to the concentration strength (Table 1). The cuticle rapidly darkened over dead larvae due to the toxic effect of the oil. The regression between concentration strength and 4^{th} instar larval mortality yielded a positive linear correlation (Y= 0.6537x-0.409, R^2= 0.9615) (Figure 37). Percent mortality, 95% confidence limit, LC_{50} and t value are summarized in Table 2. Mortality of 4^{th} instar larvae was 20% at lowest concentration (1%) while more concentrated solution of oil (2.25%) produced extreme lethal effect (100% mortality). 95% confidence limit ranged from 0.8489-10.710 with the significant t value (24.00) at 2.25%. The LC_{50} obtained with camphor oil was 1.56%. The larvae of control group exhibited only 4% mortality.

(iii). Insecticidal activity of eucalyptus oil against *Corcyra cephalonica*

The mean larval mortalities of *Corcyra cephalonica* larvae after 24 hrs and 48 hrs of exposure to increasing concentrations of eucalyptus oil via contact application is shown in Table 1. Toxic effect of eucalyptus oil depends on their concentrations and time of insect exposure. Eucalyptus oil showed the contact toxicity against *Corcyra cephalonica* larvae with the percent mortality 87.75% at 2.25% concentration after 48 hrs treatment with the 95% confidence limit ranged from 08.244-09.355 and significant t value (44). The lower dose (1%) produced 24% larval mortality at 48 hrs of exposure with oil (Table 2). LC_{50} obtained with eucalyptus is 1.43%. The larval mortality produced from the control group was only 2%.

(iv). Insecticidal activity of lemongrass oil against *Corcyra cephalonica*

The data in Table 1 shows mean larval mortality by lemongrass with different doses at first 24 and next 24 hrs of exposure. The regression between concentration strength and 4th instar larval mortality yielded positive linear correlation (Y= 0.436x-0.319, R^2= 0.9119) (Figure 39). The data regarding overall insect mortality, LC_{50}, confidence limit, t value achieved with lemongrass oil at six different concentrations along with control are given in Table 2. The results revealed that at 48 hrs exposure, the 2.25% lemongrass oil gave maximum mortality (72.91%) and increased significantly from 1% concentration which produced only 18% larval mortality. Darkened cuticle of larvae was observed when larvae died after expose to different concentrations of oil. 95% confidence limit ranged from 04.919-06.280 at significant t value (22.862; df=4, $p<0.05$) obtained with 2.25% concentration. LC_{50} value was found to be 1.92%. The control group showed 4% larval mortality which was found to be negligible as compared to the percent larval mortalities obtained with higher doses of tested essential oil.

(v). Insecticidal activity of peppermint oil against *Corcyra cephalonica*

Contact toxicity of the essential oil from peppermint against larvae of *Corcyra cephalonica* increased with increasing exposure time and concentration (Table 1). The regression between concentration strength and 4th instar larval mortality yielded a positive linear correlation (Y= 0.429x-0.278, R^2= 0.9636) (Figure 40). It is clear from the table that mortality from peppermint oil was high within 24 hrs as compared to the mortality in next 24 hrs. Dead larvae shows darkened cuticle at all concentrations of peppermint oil however some larvae became morbid exhibiting very little movement in the first 24 hrs and they eventually died following continued exposure of oil. The larvae of control group exhibited

negligible mortality. The lowest concentration (1% of peppermint oil) produced only 20% total larval mortality which was much less as comparable to the larval mortality (74%) obtained at the highest concentration (2.25%). The value of confidence limit ranged from 05.758-08.241 with the significant t value (15.652; df=4, $p<0.05$) at 2.25% concentration. The larvae of control group exhibits negligible mortality (Table 2).

(vi). Insecticidal activity of bitter orange oil against *Corcyra cephalonica*

The mean larval mortalities of *Corcyra cephalonica* after initial 24 hrs and next 24 hrs of exposure to increasing concentrations of bitter orange oil is shown in Table 1.The regression between concentration strength and 4th instar larval mortality yielded a positive linear correlation (Y= 0.386x-0.271, R^2= 0.9427) (Figure 41). Considerable differences in mortality of larvae to orange bitter oil were observed with different concentrations and time of exposure. The lowest concentration (1%) of the oil yielded 14% larval mortality while higher concentration (2.25%) yielded 58% larval mortality. All concentrations provoked significant effect on mortality (t = 06.00-22.862; df=4; $p< 0.05$) (Table 2). The probit analysis showed that *C. cephalonica* was susceptible to bitter orange oil (LC_{50}=2.03%). The larval mortality obtained with control group was 2% only.

(b). Morphogenetic and Reproductive effect of essential oils on *Corcyra cephalonica*

The female reproductive system of *Corcyra cephalonica* consists of a pair of ovaries. Each ovary is composed of four ovarioles. The four ovarioles in each ovary are polytrophic and converge at the distal ends to form a cohesive terminal bundle. The individual ovariole is distinguished in two parts, germarium and vitellarium. The extremely short part of the distal end having undifferentiated cells represents the germarium from which there is

a gradual differentiation of oogonia and trophocytes. As maturation progresses, the oocytes grow in size. Distal end of each ovariole is called vitellarium. Vitellarium forms major portion of the ovariole in which a series of immature eggs become progressively larger (Fig. 6).

There were on an average of 240-275 eggs in various stage of development in the ovaries of female adults of *Corcyra cephalonica* in the control set. Contact application of different essential oils on 4th instar larvae produced varying effect on the egg laying capacity of the emerged females (Fig. 8-16). Treatments of 4th instar *Corcyra cephalonica* larvae with different concentrations of cedarwood oil manifested in reduction of fecundity of adult females (Table 3). At two higher concentrations i.e. 2% and 2.25% of cedarwood oil, it was not possible to determine the fecundity of adults as there was 100% larval mortality within 48 hrs of treatment. At lower concentrations viz. 1%, 1.25%, 1.5% and 1.75% cedarwood oil, severe anatomical abnormalities developed in ovarioles. There was overall reduction in size of ovarioles due to shrinkage in ovariole length, reduction in number of developing oocytes etc. (Fig. 8-11). Moreover, compared to the control ovarioles which showed progressive and orderly development of ova along the entire length (Fig. 7), the affected ovarioles exhibited random, unorganized and uneven development of ova with several empty spaces (Fig. 8-11). In many cases the immature, small ova were interposed between large ova and vice versa along the length of ovariole (Fig. 10 & 11). Application of other essential oils viz. camphor, eucalyptus, peppermint, lemongrass and orange bitter even at high concentration produced negligible effect on reproductive system (Fig. 12-16) Furthermore, apparently no gross morphogenetic abnormalities viz. abnormal crumpled wings, larval-pupal mosaic, pupal-adult mosaic etc were induced by any of the tested essential oils at different concentrations.

(B). Combination of essential oils

(a). Insecticidal activity of various combination of essential oils against *Corcyra cephalonica*

The mean of the total larval mortality by the application of different combination of essential oils i.e. cedarwood+eucalyptus, cedarwood+camphor, cedarwood+peppermint, cedarwood+lemongrass, cedarwood+bitterorange, eucalyptus+camphor, eucalyptus+peppermint, eucalyptus+lemongrass, eucalyptus+bitterorange, camphor+peppermint, camphor+lemongrass, camphor+bitterorange, peppermint+lemongrass, peppermint+bitterorange, lemongrass+bitterorange on 4th instar larvae of *Corcyra cephalonica* along with control (acetone) is given in (Table 4).

All the combination of essential oils except lemongrass with bitter orange oil resulted in 100% mortality at different concentrations as shown in table (Table 5). Cedarwood + eucalyptus oil was the most toxic to 4th instar larvae. The regression between concentration strength and 4th instar larval mortality yielded a positive linear correlation (Y= 0.477x-0.047, R^2= 0.7951) (Figure 42). 100% mortality occurred at 1.75% concentration within 24 hrs. The highest dose of lemongrass with bitter orange i.e. 2.25% produced 81.25% larval mortality within 48 hrs while at its lower dose i.e. 1% concentration it resulted in 28%. Fig shows the regression between concentration strength and percent larval mortality treated with different combination of essential oils yields positive linear correlation. The LC_{50} values of different combination of essential oils listed in Table 5. Thus the toxicity from different essential oils can be summarized as follows:

Cedarwood + eucalyptus > cedarwood + camphor > cedarwod + peppermint > cedarwood + lemongrass > cedarwood + bitterorange > eucalyptus + camphor > eucalyptus + peppermint > eucalyptus + lemongrass > eucalyptus + bitterorange > camphor + peppermint > camphor + lemongrass > camphor + bitterorange > peppermint + lemongrass > peppermint + bitterorange > lemongrass + bitter orange oil.

(b). Morphogenetic and Reproductive effect of essential oils on *Corcyra cephalonica*

The female reproductive system of *Corcyra cephalonica* consists of a pair of ovaries. Each ovary was composed of four ovarioles. Distal end of each ovariole is called germarium which is followed by the vitellarium. Vitellarium includes major portion of the ovariole in which a series of immature eggs become progressively larger (Fig. 6).There were on an average of 240-275 eggs in various stage of development in the ovaries of control female adults of *Corcyra cephalonica.* The effect of different combination of cedarwood with eucalyptus, cedarwood with peppermint and cedarwood with camphor, cedarwood with lemongrass and cedarwood with bitter orange oil on fecundity expressed as the number of eggs per female is summarized in Table 3. Effect of different combination of cedarwood oil at different concentrations manifested itself in the treated larvae as a reduction in fecundity. At different concentrations of combination of cedarwood with eucalyptus, cedarwood with peppermint and cedarwood with camphor oil empty spaces were created within the ovarioles presumably due to resorption of oocytes and also showed shrinkage in the whole ovary as only a few eggs were developed as shown in Fig.17-24. In contrast combination of cedarwood with lemongrass, cedarwood with bitterorange oil exhibited reduction in number of eggs but not in such extent that were showed by the above combinations and also there found no deformity in the structure of ovaries of treated adults (Fig. 25-26). At high concentrations, rest of the combination of essential oils there was negligible effect on reproductive system (Fig. 27-35). No morphogenetic effect induced by the tested essential oils.

(II). Fumigant bioassay of essential oils

(A). *Corcyra cephalonica* exposed to vapour action of individual essential oils

(a). Insecticidal activity

(i). Insecticidal activity of eucalyptus oil against *Corcyra cephalonica*

Larvicidal action of eucalyptus oil was tested against newly moulted 4th instar *Corcyra cephalonica* larvae by fumigation in six different concentrations i.e. 200, 250, 300, 350, 400 and 450 μlL^{-1} of air (Table 7). The essential oil of eucalyptus killed *Corcyra cephalonica* larvae by fumigant action. Values of % corrected mortality, t, LC_{50} are summarized in Table 8. The LC_{50} of cedarwood oil was foundto be 398 μlL^{-1} at 24 hrs against 4th instar larvae. The regression analysis showed a concentration dependent significant positive correlation of the oil with larval mortality (Y=0.0018x-0.2206, R^2=0.9881) (Figure 57). The fumigant toxicity significantly increased with increased concentration with the percent larval mortality reaching 57.14% at the dosage of 450 μlL^{-1} air. Mortality exhibited by the exposure of larvae to the lowest concentration i.e. 200 μlL^{-1} was 10.20%. The larval death in the control was only 2%.

(ii). Insecticidal activity of cedarwood oil against *Corcyra cephalonica*

Fumigant toxicity of the essential oil from cedarwood against larvae of *Corcyra cephalonica* increased with increasing exposure time (Table 7). The regression analysis showed a concentration dependent significant positive correlation of the oil with larval mortality (Y=0.0018x-0.2872, R^2= 0.9899) (Figure 58). Table 8 gives the percent larval mortality, % corrected mortality, t and 95% Confidence limit for each concentration of cedarwood oil on *Corcyra cephalonica* larvae. The cedarwood oil showed the moderate

fumigant toxicity against larvae with the 54 percent larval mortality after 24 hr treatment at 450 μlL^{-1} air (higher concentration) and weak toxicity against *Corcyra cephalonica* larvae at 200 μlL^{-1} with only 10% larval mortality. The essential oil of cedarwood possessed fumigant toxicity against 4th instar larvae with a LC_{50} of 434 μlL^{-1}.

(iii). Insecticidal activity of peppermint oil against *Corcyra cephalonica*

Table 7 showed comparative effectiveness of different concentrations of peppermint oil at 200, 250, 300, 350, 400 and 450 μlL^{-1} concentrations at 24 hr. Regression analysis of peppermint oil showed concentration based significant correlation of the oil fumes with percent larval mortality ($Y=0.0018x-0.2931$, $R^2= 0.985$) (Fig 59). The results of LC_{50}, percent larval mortality, % corrected mortality, t and 95% Confidence limit for the *Corcyra cephalonica* larvae are presented in the Table 8. The *Corcyra cephalonica* larvae had different sensitivity according to the different concentrations of the peppermint oil. At concentration of 200 μlL^{-1} air, peppermint oil caused 4.17% larval mortality for *Corcyra cephalonica* larvae and then increased to 52.08% at the highest concentration (450 μlL^{-1}). The LC_{50} value obtained with peppermint oil was 442 μlL^{-1} of air.

(iv). Insecticidal activity of camphor oil against *Corcyra cephalonica*

The effect of camphor oil on mortality at 24 hr was presented as Mean±S.E in Table 7. The regression analysis showed a concentration dependent significant correlation of the oil with larval mortality ($Y=0.0018x-0.3128$, $R^2= 0.9464$) (Figure 60). There was a positive relationship between dose of the oil and larval mortality of *Corcyra cephalonica*. The mortality rate increased with the concentration of the camphor oil. With the lower concentration 200 μlL^{-1}, camphor oil induced 8% larval mortality while at the highest concentration it exhibited 52% larval mortality. The LC_{50} of camphor oil was

444 μlL^{-1}. Control treatment induced only 2% larval mortality (Table 8). 95% confidence limit for the highest concentration of camphor oil was found to be 4.12-5.87.

(v). Insecticidal activity of lemongrass oil against *Corcyra cephalonica*

The regression between concentration strength and 4th instar larval mortality yields a positive linear correlation (Y= 0.0017x-0.343, R^2= 0.9287) (Figure 61). The data regarding overall insect mortality, LC_{50}, confidence limit, t value achieved with lemongrass oil at six different concentrations along with control are given in Table 8. The results revealed that at 24 hrs exposure, the 450 μlL^{-1} gave larval mortality (46%) and differ significantly from 1% concentration which produced only 4% larval mortality. 95% confidence limit ranged from 2.358-6.041. The control group showed 4% larval mortality which was found to be same with the mortality found at lowest concentration.

(vi). Insecticidal activity of bitter orange oil against *Corcyra cephalonica*

The lowest concentration 200 μlL^{-1} of bitter orange oil produced only 2% total larval mortality while the highest dose induced 44% larval mortality after 24 hrs of exposure. The value of confidence limit ranged from 3.161-5.238 at the 450 μlL^{-1}. The regression between concentration strength and 4th instar larval mortality yields a positive linear correlation (Y=0.0017x-0.3634, R^2= 0.9287) (Figure 62).

(B). *Corcyra cephalonica* when exposed to vapour action of essential oils in different combinations

The mean of the total larval mortalities of *Corcyra cephalonica* after 24 hrs of exposure to increasing concentrations of tested volatiles oils is shown in Table 9. Table 10 shows the fumigant effect of each combination of

essential oil at 200, 250, 300, 350, 400 and 450 μlL^{-1} of air respectively. *Corcyra cephalonica* larvae when exposed to vapours of each combination of essential oils at 450 μlL^{-1} concentration, the highest susceptibility was shown for cedarwood + eucalyptus oil having (%Corrected mortality=77.55%). At similiar concentrations, the combinations camphor + lemongrass, camphor + bitterorange oil, and bitterorange + lemongrass oil showed mortality < 50% within 24 hrs of exposure. The toxicity of these combinations of essential oils can be summerized on the basis of their % correted mortality (Table 10):

Eucalyptus + cedarwood > cedarwood + peppermint > cedarwood + camphor > eucalyptus + peppermint > eucalyptus + camphor > cedarwood + lemongrass > eucalyptus + lemongrass = cedarwood + bitterorange > eucalyptus + bitterorange = camphor + peppermint > peppermint + lemongrass > peppermint + bitterorange > camphor + lemongrass > camphor + bitterorange > bittterorange + lemongrass oil.

(b). Morphogenetic and Reproductive effect of essential oils on *Corcyra cephalonica*

There was no morphogenetic and reproductive effect induced by the essential oils in fumigation treatment.

Table 1. Relative mortality of *C. cephalonica* exposed to different essential oils via contact application

Essential oils	Conc. %	Mean ± S.E at 24 hrs	Mean ± S.E at 24 hrs
Cedarwood oil	1.00	2.6 ± 0.244	2.0 ± 0.199
	1.25	3.2 ± 0.373	4.0 ± 0.244
	1.50	4.2 ± 0.373	1.2 ± 0.373
	1.75	5.6 ± 0.399	2.0 ± 0.447
	2.00	10 ± 0.000	0.0 ± 0.000
	2.25	10 ± 0.000	0.0 ± 0.000
Camphor oil	Control	4.0 ± 0.244	0.0 ± 0.000
	1.00	1.4 ± 0.244	8.0 ± 0.199
	1.25	2.4 ± 0.244	1.0 ± 0.447
	1.50	3.6 ± 0.599	1.4 ± 0.399
	1.75	4.6 ± 0.509	1.6 ± 0.244
	2.00	6.4 ± 0.506	1.0 ± 0.316
	2.25	10 ± 0.000	0.0 ± 0.000
	Control	2.0 ± 0.000	2.0 ± 0.199
Eucalyptus oil	1.00	2.0 ± 0.000	4.0 ± 0.244
	1.25	3.8 ± 0.199	0.0 ± 0.000
	1.50	5.0 ± 0.000	2.0 ± 0.199
	1.75	6.0 ± 0.000	8.0 ± 0.199
	2.00	7.6 ± 0.244	4.0 ± 0.244
	2.25	8.0 ± 0.000	1.0 ± 0.000
	Control	2.0 ± 0.199	0.0 ± 0.199

Lemongrass oil	1.00	1.0 ± 0.000	8.0 ± 0.344
	1.25	8.0 ± 0.199	1.6 ± 0.357
	1.50	1.6 ± 0.244	1.0 ± 0.565
	1.75	3.2 ± 0.489	6.0 ± 0.219
	2.00	4.4 ± 0.244	1.0 ± 0.000
	2.25	6.8 ± 0.373	7.0 ± 0.193
	Control	2.0 ± 0.199	2.2 ± 0.178
Peppermint oil	1.00	2.0 ± 0.000	0.0 ± 0.000
	1.25	2.2 ± 0.199	2.0 ± 0.199
	1.50	3.0 ± 0.000	4.0 ± 0.244
	1.75	3.8 ± 0.373	6.0 ± 0.244
	2.00	4.4 ± 0.244	1.2 ± 0.199
	2.25	6.8 ± 0.373	6.0 ± 0.244
	Control	2.0 ± 0.199	2.0 ± 0.199
Bitter orange oil	1.00	1.2 ± 0.000	2.0 ± 0.000
	1.25	1.4 ± 0.000	4.0 ± 0.000
	1.50	2.0 ± 0.199	6.0 ± 0.000
	1.75	4.2 ± 0.199	6.0 ± 0.000
	2.00	4.4 ± 0.000	4.0 ± 0.000
	2.25	5.4 ± 0.244	4.0 ± 0.199
	Control	2.0 ± 0.000	0.0 ± 0.199

Mean of 5 replicates each containing 10 larvae

Table 2. Insecticidal activity of essential oils against *C. cephalonica* at different concentrations in 48 hrs via contact application

Essential oils	Concs %	% Mortality	% Corrected Mortality	LC_{50}	t(df)*	95% Confidence Limit	
						Lower	Upper
Cedarwood oil	1.00	28	25.00		09.798(4)	1.719	3.080
	1.25	36	33.33		08.552(4)	2.161	4.238
	1.50	54	52.08		15.811(4)	4.122	5.877
	1.75	74	72.91	1.37	22.136(4)	6.122	7.877
	2.00	100	100.00		39.192(4)	8.919	10.280
	2.25	100	100.00		39.192(4)	8.919	10.280
	Control	4					
Camphor oil	1.00	20	16.66		03.138(4)	0.184	3.015
	1.25	34	31.25		06.708(4)	1.758	4.241
	1.50	50	47.91		09.021(4)	3.184	6.015
	1.75	62	60.41	1.56	09.947(4)	4.181	7.418
	2.00	74	72.91		15.652(4)	5.758	8.241
	2.25	100	100.00		24.000(4)	8.489	10.710
	Control	4					
Eucalyptus oil	1.00	24	22.44		05.880(4)	1.161	3.238
	1.25	38	36.73		14.697(4)	2.919	4.280
	1.50	52	51.02		17.177(4)	3.818	4.313
	1.75	68	67.34	1.43	26.944(4)	5.919	7.280
	2.00	80	79.59		39.000(4)	6.919	7.313
	2.25	88	87.75		44.000(4)	7.244	8.355
	Control						
Lemongrass oil	1.00	18	14.58		06.000(4)	0.644	1.755
	1.25	24	20.83		06.532(4)	0.919	2.280
	1.50	26	22.91		04.707(4)	0.984	3.815
	1.75	38	35.41	1.92	18.779(4)	3.919	5.280
	2.00	54	52.08		12.829(4)	3.761	5.838
	2.25	74	72.91		22.862(4)	4.919	6.280
	Control	4					

Essential oils	Concs %	% Mortality	% Corrected Mortality	LC_{50}	t(df)*	95% Confidence Limit	
						Lower	Upper
Peppermint oil	1.00	20	16.66			0.919	2.280
	1.25	24	20.83		06.325(4)	1.122	2.877
	1.50	34	31.25		06.708(4)	1.758	4.241
	1.75	44	41.66	1.83	08.944(4)	2.758	5.241
	2.00	56	54.16		10.614(4)	3.83	6.560
	2.25	74	72.91		15.652(4)	5.758	8.241
	Control	4					
Bitter orange oil	1.00	14	12.24		06.000(4)	0.644	1.755
	1.25	18	16.32		06.532(4)	0.919	2.280
	1.50	26	24.48		04.707(4)	0.984	3.815
	1.75	48	46.93	2.03	18.779(4)	3.919	5.280
	2.00	50	48.97		11.500(4)	3.489	5.710
	2.25	58	57.14		22.862(4)	4.91	6.280
	Control	2					

LC_{50}=lethal concentration that kill 50% of the exposed larvae; 50 larvae (5 replicates of 10 each) were treated at each dose; *Significant at $P<0.05$.

Table 3. Relative Mean±S.E of egg laying of treated *C. cephalonica* in contact application

Essential oil	Conc. (%)	Mean ± SE (egg laying)
Cedarwood oil	1.00	141.6 ± 1.734
	1.25	123.6 ± 1.614
	1.50	82.8 ± 0.912
	1.75	67.0 ± 2.050
	2.00	Nil
	2.25	Nil
	Control	267.0 ± 2.933
Camphor oil	1.00	261.2 ± 4.255
	1.25	262.6 ± 3.976
	1.50	261.6 ± 2.426
	1.75	264.2 ± 2.917
	2.00	258.2 ± 4.255
	2.25	Nil
	Control	266.0 ± 2.465
Eucalyptus oil	1.00	266.6 ± 1.538
	1.25	265.4 ± 3.169
	1.50	261.0 ± 3.847
	1.75	260.8 ± 4.199
	2.00	262.4 ± 3.389
	2.25	265.4 ± 2.632
	Control	269.4 ± 1.402
Peppermint oil	1.00	263.2 ± 3.291
	1.25	260.6 ± 4.936
	1.50	259.4 ± 4.396
	1.75	264.0 ± 2.785
	2.00	268.8 ± 2.644
	2.25	259.8 ± 4.520
	Control	264.6 ± 2.539
Lemongrass oil	1.00	268.8 ± 2.644
	1.25	261.2 ± 5.078
	1.50	262.6 ± 5.210
	1.75	263.8 ± 4.255
	2.00	264.4 ± 2.961
	2.25	261.0 ± 3.763
	Control	244.0 ± 5.258
Bitter orange oil	1.00	266.0 ± 3.006
	1.25	263.8 ± 4.394
	1.50	262.2 ± 3.943
	1.75	259.6 ± 4.729
	2.00	261.0 ± 4.724
	2.25	261.6 ± 3.853
	Control	260.6 ± 3.904

Mean of 5 replicates each containing 10 larvae

Table 4. Relative mortality of *C. cephalonica* exposed to different essential oils via contact application

Essential oils	Conc. %	Mean ± SE at 24hrs (larval mortality)	Mean ± SE at next 24 hrs (larval mortality)
Cedarwood+Eucalyptus	1.00	03 ± 0.317	3.8 ± 0.357
	1.25	6.2 ± 0.374	6.8 ± 0.178
	1.50	8.2 ± 0.374	8.8 ± 0.178
	1.75	10 ± 0.000	10 ± 0.000
	2.00	10 ± 0.000	10 ± 0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178
Cedarwood+Camphor	1.00	3.6 ± 0.244	4.2 ± 0.438
	1.25	4.2 ± 0.199	5.2 ± 0.178
	1.50	5.4 ± 0.244	6.2 ± 0.178
	1.75	8.2 ± 0.199	8.8 ± 0.178
	2.00	10 ± 0.000	10 ± 0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178
Cedarwood+Peppermint	1.00	2.4±0.244	3.2 ± 0.178
	1.25	3.2 ± 0.199	4.2 ± 0.178
	1.50	5.2 ± 0.199	6.2 ± 0.178
	1.75	9.8 ± 0.199	10 ± 0.000
	2.00	10 ± 0.000	10 ± 0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.000	0.2 ± 0.178
Cedarwood+Lemongrass	1.00	03 ± 0.317	3.8 ± 0.178
	1.25	3.4 ± 0.677	4.8 ± 0.178
	1.50	4.8 ± 0.489	6.2 ± 0.178
	1.75	9.4 ± 0.244	10 ± 0.000
	2.00	10 ± 0.000	10 ± 0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.4 ± 0.244	0.2 ± 0.178

Essential oils	Conc. %	Mean ± SE at 24hrs (larval mortality)	Mean ± SE at next 24 hrs (larval mortality)
Cedarwood+Bitterorange	1.00	2.6 ± 0.399	3.4 ± 0.357
	1.25	3.6 ± 0.399	04 ± 0.489
	1.50	5.2 ± 0.489	06 ± 0.565
	1.75	9.8 ± 0.199	10 ± 0.000
	2.00	10 ± 0.000	10 ±0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.4 ± 0.219
Eucalyptus+Camphor	1.00	2.6 ± 0.244	4.2 ± 0.178
	1.25	04 ± 0.199	05 ± 0.000
	1.50	5.4 ± 0.244	6.2 ± 0.178
	1.75	6.2 ± 0.199	6.8 ± 0.178
	2.00	7.4 ± 0.244	8.2 ± 0.178
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178
Eucalyptus+Peppermint	1.00	2.8 ± 0.374	3.2 ± 0.178
	1.25	3.8 ± 0.199	4.2 ± 0.178
	1.50	5.2 ± 0.199	5.8 ±0.178
	1.75	6.8 ± 0.489	7.6 ± 0.357
	2.00	9.6 ± 0.244	10 ± 0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178
Eucalyptus+Lemongrass	1.00	1.6 ± 0.399	2.2 ± 0.178
	1.25	03 ± 0.317	3.8 ± 0.178
	1.50	4.4 ± 0.244	5.2 ± 0.178
	1.75	6.6 ±0.244	7.6 ± 0.219
	2.00	10 ± 0.000	10 ± 0.000
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178

Essential oils	Conc. %	Mean ± SE at 24hrs (larval mortality)	Mean ± SE at next 24 hrs (larval mortality)
Eucalyptus+Bitterorange	1.00	02 ± 0.447	2.4 ± 0.219
	1.25	03 ± 0.317	3.8 ± 0.178
	1.50	4.4 ± 0.244	5.2 ± 0.178
	1.75	5.8 ± 0.374	6.6 ± 0.219
	2.00	7.8 ± 0.199	8.4 ± 0.219
	2.25	9.2 ± 0.374	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178
Camphor+Peppermint	1.00	0.6 ± 0.244	02 ± 0.000
	1.25	1.8 ± 0.374	2.6 ± 0.219
	1.50	3.4 ± 0.244	3.8 ± 0.334
	1.75	4.8 ± 0.374	5.6 ± 0.219
	2.00	7.4 ± 0.244	8.2 ± 0.334
	2.25	9.6 ± 0.244	10 ± 0.000
	Control	0.4 ± 0.244	0.4 ± 0.219
Camphor+Lemongrass	1.00	1.2 ± 0.374	1.8 ± 0.178
	1.25	1.8 ± 0.374	2.2 ± 0.178
	1.50	2.8 ± 0.374	3.2 ± 0.178
	1.75	6.4 ± 0.244	6.8 ± 0.178
	2.00	6.6 ± 0.244	7.4 ± 0.219
	2.25	9.2 ± 0.199	10 ± 0.000
	Control	0.4 ± 0.244	0.4 ± 0.219
Camphor+Bitterorange	1.00	1.4 ± 0.244	2.2 ± 0.178
	1.25	2.6 ±0.399	3.0 ± 0.282
	1.50	3.2 ± 0.199	3.8 ± 0.178
	1.75	4.8 ± 0.374	6.0 ± 0.000
	2.00	6.2 ± 0.199	7.2 ± 0.178
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178

Essential oils	Conc. %	Mean ± SE at 24hrs (larval mortality)	Mean ± SE at next 24 hrs (larval mortality)
Eucalyptus+Bitterorange	1.00	02 ± 0.447	2.4 ± 0.219
	1.25	03 ± 0.317	3.8 ± 0.178
	1.50	4.4 ± 0.244	5.2 ± 0.178
	1.75	5.8 ± 0.374	6.6 ± 0.219
	2.00	7.8 ± 0.199	8.4 ± 0.219
	2.25	9.2 ± 0.374	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178
Camphor+Peppermint	1.00	0.6 ± 0.244	02 ± 0.000
	1.25	1.8 ± 0.374	2.6 ± 0.219
	1.50	3.4 ± 0.244	3.8 ± 0.334
	1.75	4.8 ± 0.374	5.6 ± 0.219
	2.00	7.4 ± 0.244	8.2 ± 0.334
	2.25	9.6 ± 0.244	10 ± 0.000
	Control	0.4 ± 0.244	0.4 ± 0.219
Camphor+Lemongrass	1.00	1.2 ± 0.374	1.8 ± 0.178
	1.25	1.8 ± 0.374	2.2 ± 0.178
	1.50	2.8 ± 0.374	3.2 ± 0.178
	1.75	6.4 ± 0.244	6.8 ± 0.178
	2.00	6.6 ± 0.244	7.4 ± 0.219
	2.25	9.2 ± 0.199	10 ± 0.000
	Control	0.4 ± 0.244	0.4 ± 0.219
Camphor+Bitterorange	1.00	1.4 ± 0.244	2.2 ± 0.178
	1.25	2.6 ±0.399	3.0 ± 0.282
	1.50	3.2 ± 0.199	3.8 ± 0.178
	1.75	4.8 ± 0.374	6.0 ± 0.000
	2.00	6.2 ± 0.199	7.2 ± 0.178
	2.25	10 ± 0.000	10 ± 0.000
	Control	0.2 ± 0.199	0.2 ± 0.178

Table 5. Insecticidal activity of essential oils against *C. cephalonica* at different concentration at 48 h. via contact application

Essential oils	Concs. %	% Mortality	% Corrected Mortality	LC_{50} (%)	t(df)*	95% Confidence	
						Lower	Upper
Cedarwood+Eucalyptus	1.00	38	36.73		07.060(4)	2.184	5.015
	1.25	68	67.35		26.944(4)	5.919	7.280
	1.50	88	87.76		21.500(4)	7.489	9.710
	1.75	100	100.00	1.05	49.000(4)	9.244	10.355
	2.00	100	100.00		49.000(4)	9.244	10.355
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					
Cedarwood+camphor	1.00	42	40.82		06.325(4)	2.244	5.755
	1.25	52	51.02		15.811(4)	4.122	5.877
	1.50	62	61.22		18.974(4)	5.122	6.877
	1.75	88	87.76		35.109(4)	7.919	9.280
	2.00	100	100.00		49.000(4)	9.244	10.355
	2.25	100	100.00	1.18	49.000(4)	9.244	10.355
	Control	2					
Cedarwood+Peppermint	1.00	32	30.61		09.487(4)	2.122	3.877
	1.25	42	40.82		12.464(4)	3.122	4.877
	1.50	62	61.22		18.974(4)	5.122	6.877
	1.75	100	100.00	1.26	49.000(4)	9.244	10.355
	2.00	100	100.00		49.000(4)	9.244	10.355
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					

Essential oils	Concs. %	% Mortality	% Corrected Mortality	LC_{50} (%)	t(df)*	95% Confidence	
						Lower	Upper
Cedarwood+Lemongrass	1.00	34	31.25		06.708(4)	1.758	4.241
	1.25	40	37.50		07.060(4)	2.184	5.015
	1.50	60	58.33		10.983(4)	4.184	7.015
	1.75	100	100.00	1.27	39.192(4)	8.919	10.280
	2.00	100	100.00		39.192(4)	8.919	10.280
	2.25	100	100.00		39.192(4)	8.919	10.280
	Control	4					
Cedarwood+Bitterorange	1.00	38	36.73		09.487(4)	2.122	3.877
	1.25	48	46.94		08.944(4)	2.758	5.241
	1.50	62	61.00		22.862(4)	4.919	6.280
	1.75	100	100.00	1.27	18.500(4)	6.289	8.510
	2.00	100	100.00		49.000(4)	9.244	10.355
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					
Eucalyptus+Camphor	1.00	42	40.82		12.649(4)	3.122	4.877
	1.25	50	48.98		24.000(4)	4.244	5.355
	1.50	62	61.22		18.974(4)	5.122	6.877
	1.75	68	67.35	1.29	26.944(4)	5.919	7.280
	2.00	82	81.63		25.298(4)	7.122	8.877
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					

Essential oils	Concs. %	% Mortality	% Corrected Mortality	LC_{50} (%)	t(df)*	95% Confidence	
						Lower	Upper
Eucaylptus+Peppermint	1.00	32	30.61		09.487(4)	2.112	3.877
	1.25	42	40.82		08.944(4)	2.758	5.241
	1.50	58	57.14		22.862(4)	4.919	6.280
	1.75	76	75.51	1.32	18.500(4)	6.289	8.510
	2.00	100	100.00		49.000(4)	9.244	10.355
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					
Eucalyptus+Lemongrass	1.00	22	20.41		06.325(4)	1.122	2.877
	1.25	38	36.73		14.697(4)	2.919	4.280
	1.50	52	51.02		15.811(4)	4.122	5.877
	1.75	76	75.51	1.38	18.500(4)	6.289	8.510
	2.00	100	100.00		49.000(4)	9.244	10.355
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					
Eucalyptus+Bitterorange	1.00	24	22.45		11.000(4)	1.644	2.755
	1.25	38	36.73		14.697(4)	2.919	4.280
	1.50	52	51.02		15.811(4)	4.122	5.877
	1.75	66	65.31	1.41	26.128(4)	5.719	7.080
	2.00	84	83.67		21.915(4)	7.161	9.238
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					

Essential oils	Concs. %	% Mortality	% Corrected Mortality	LC_{50} (%)	t(df)*	95% Confidence	
						Lower	Upper
Peppermint+Lemongrass	1.00	22	18.75		04.811(4)	0.761	2.838
	1.25	28	25.00		09.798(4)	1.719	3.080
	1.50	42	39.58		10.156(4)	2.761	4.838
	1.75	62	60.42	1.58	15.501(4)	4.761	6.838
	2.00	100	100.00		39.192(4)	8.919	10.280
	2.25	100	100.00		39.192(4)	8.919	10.280
	Control	4					
Peppermint+Bitterorange	1.00	24	22.45		11.000(4)	1.644	2.755
	1.25	32	30.61		06.708(4)	1.758	4.241
	1.50	38	36.73		09.000(4)	2.489	4.71
	1.75	46	44.90	1.77	11.000(4)	3.289	5.51
	2.00	68	67.35		26.944(4)	5.919	7.28
	2.25	100	100.00		49.000(4)	9.244	10.355
	Control	2					
Lemongrass+Bitterorange	1.00	16	12.50		03.207(4)	0.161	2.238
	1.25	28	25.00		09.798(4)	1.719	3.08
	1.50	36	33.33		16.000(4)	2.644	3.755
	1.75	46	43.75	1.8	11.225(4)	3.161	5.238
	2.00	66	64.58		10.633(4)	4.581	7.818
	2.25	82	81.25		20.846(4)	6.761	8.838
	Control	4					

Lc_{50} = lethal concentration that kill 50% of the exposed larvae; 50 larvae (5 replicates of 10 each) were treated at each dose; *Significant at $P<0.05$.

Table 6. Relative Mean ± S.E of egg laying of treated *C. cephalonica* in contact application

Essential oil	Conc. (%)	Mean ± SE (egg laying)
Cedarwood+Eucalyptus	1.00	34.0 ± 0.707
	1.25	29.4 ± 1.248
	1.50	23.4 ± 0.927
	1.75	Nil
	2.00	Nil
	2.25	Nil
	Control	261.2 ± 5.258
Cedarwood+Peppermint	1.00	44.0 ± 0.707
	1.25	33.2 ± 0.969
	1.50	31.4 ± 0.509
	1.75	Nil
	2.00	Nil
	2.25	Nil
	Control	260.6 ± 4.936
Cedarwood+Camphor	1.00	54.2 ± 0.860
	1.25	42.0 ± 0.707
	1.50	26.2 ± 1.067
	1.75	Nil
	2.00	Nil
	2.25	Nil
	Control	263.2 ± 3.291
Cedarwood+Lemongrass	1.00	205.8 ± 1.593
	1.25	195.0 ± 1.139
	1.50	185.2 ± 0.860
	1.75	Nil
	2.00	Nil
	2.25	Nil
	Control	264.6 ± 2.539
Cedarwood+Bitterorange	1.00	208.4 ± 1.938
	1.25	196.8 ± 1.157
	1.50	186.8 ± 1.496
	1.75	Nil
	2.00	Nil
	2.25	Nil
	Control	260.6 ± 3.904
Eucayptus + Camphor	1.00	269.8 ± 3.291
	1.25	266.6 ± 1.538
	1.50	265.4 ± 2.632
	1.75	269.4 ± 1.402
	2.00	259.8 ± 4.520
	2.25	259.4 ± 4.396
	Control	264.4 ± 2.961

Essential oil	Conc. (%)	Mean ± SE (egg laying)
Eucayptus + Peppermint	1.00	262.6 ± 5.210
	1.25	262.4 ± 3.389
	1.50	265.4 ± 2.632
	1.75	269.4 ± 1.402
	2.00	263.2 ± 3.291
	2.25	260.6 ± 4.936
	Control	259.4 ± 4.396
Eucalyptus + Lemongrass	1.00	264.0 ± 2.785
	1.25	268.8 ± 2.644
	1.50	259.8 ± 4.520
	1.75	264.6 ± 2.539
	2.00	268.8 ± 2.644
	2.25	261.2 ± 5.078
	Control	262.6 ± 5.210
Eucayptus + Bitter orange	1.00	268.8 ± 2.644
	1.25	261.2 ± 5.078
	1.50	262.6 ± 5.210
	1.75	263.8 ± 4.255
	2.00	264.4 ± 2.961
	2.25	261.0 ± 3.763
	Control	244.0 ± 5.258
Camphor + Peppermint	1.00	266.0 ± 3.006
	1.25	263.8 ± 4.394
	1.50	262.2 ± 3.943
	1.75	259.6 ± 4.729
	2.00	261.0 ± 4.724
	2.25	261.6 ± 3.853
	Control	260.6 ± 3.904
Camphor + Lemongrass	1.00	268.8 ± 2.644
	1.25	261.2 ± 5.078
	1.50	262.6 ± 5.210
	1.75	268.8 ± 2.644
	2.00	261.2 ± 5.078
	2.25	262.6 ± 5.210
	Control	263.8 ± 4.255

Essential oil	Conc. (%)	Mean ± SE (egg laying)
Camphor + Bitter orange	1.00	264.4 ± 2.961
	1.25	261.0 ± 3.763
	1.50	265.4 ± 3.169
	1.75	261.0 ± 3.847
	2.00	260.8 ± 4.199
	2.25	262.4 ± 3.389
	Control	265.4 ± 2.632
Peppermint + Lemongrass	1.00	269.4 ± 1.402
	1.25	263.2 ± 3.291
	1.50	260.6 ± 4.936
	1.75	259.4 ± 4.396
	2.00	264.0 ± 2.785
	2.25	268.8 ± 2.644
	Control	259.8 ± 4.520
Lemongrass + Bitter orange	1.00	265.4 ± 3.169
	1.25	261.0 ± 3.847
	1.50	260.8 ± 4.199
	1.75	262.4 ± 3.389
	2.00	265.4 ± 2.632
	2.25	265.4 ± 2.632
	Control	269.4 ± 1.402

Mean of 5 relicates each containing 10 larvae

Table 7. Mortality of *Corcyra cephalonica* exposed to different essential oils via fumigation application

Essential oils	Concs.	Mean ± SE at 24 hrs
Cedarwood oil	200µlL^{-1}	1.0 ± 0.316
	250µlL^{-1}	1.4 ± 0.509
	300µlL^{-1}	2.6 ± 0.600
	350µlL^{-1}	3.4 ± 0.400
	400µlL^{-1}	4.4 ± 0.400
	450µlL^{-1}	5.4 ± 0.400
	Control	0.2 ± 0.178
Eucalyptus oil	200µlL^{-1}	1.2 ± 0.374
	250µlL^{-1}	2.6 ± 0.244
	300µlL^{-1}	3.2 ± 0.374
	350µlL^{-1}	4.2 ± 0.374
	400µlL^{-1}	5.2 ± 0.374
	450µlL^{-1}	5.8 ± 0.200
	Control	0.2 ± 0.200
Peppermint oil	200µlL^{-1}	0.8 ± 0.374
	250µlL^{-1}	1.6 ± 0.244
	300µlL^{-1}	2.2 ± 0.583
	350µlL^{-1}	3.4 ± 0.244
	400µlL^{-1}	4.0 ± 0.632
	450µlL^{-1}	5.4 ± 0.400
	Control	0.4 ± 0.244
Camphor oil	200µlL^{-1}	0.8 ± 0.200
	250µlL^{-1}	1.2 ± 0.200
	300µlL^{-1}	2.2 ± 0.374
	350µlL^{-1}	2.4 ± 0.400
	400µlL^{-1}	4.2 ± 0.200
	450µlL^{-1}	5.2 ± 0.489
	Control	0.2 ± 0.200
Lemongrass oil	200µlL^{-1}	0.4 ± 0.244
	250µlL^{-1}	0.8 ± 0.374
	300µlL^{-1}	1.4 ± 0.600
	350µlL^{-1}	1.8 ± 0.489
	400µlL^{-1}	3.6 ± 0.400
	450µlL^{-1}	4.6 ± 0.600
	Control	0.4 ± 0.244
Orange bitter oil	200µlL^{-1}	0.2 ± 0.200
	250µlL^{-1}	0.6 ± 0.400
	300µlL^{-1}	1.2 ± 0.583
	350µlL^{-1}	1.6 ± 0.600
	400µlL^{-1}	3.4 ± 0.244
	450µlL^{-1}	4.4 ± 0.509
	Control	0.2 ± 0.200

Mean of 5 replicates each containing 10 larvae

Table 8. Insecticidal activity of essential oils against *C. cephalonica* at different concentrations via contact application

Essential oils	Concs %	% Mortality	% Corrected mortality	LC_{50} %	t (df)*	95% Confidence limit	
						Lower	Upper
Cedarwood oil	200µlL^{-1}	10	8.16		04.000(4)	0.224	1.355
	250µlL^{-1}	14	12.24		03.207(4)	0.161	2.238
	300µlL^{-1}	26	24.49		04.707(4)	0.984	3.185
	350µlL^{-1}	34	32.65	434	08.552(4)	2.161	4.238
	400µlL^{-1}	44	42.86		11.225(4)	3.161	5.238
	450µlL^{-1}	54	53.06		13.898(4)	4.161	6.238
	Control	2					
Eucalyptus oil	200µlL^{-1}	12	10.20		03.162(4)	0.122	1.877
	250µlL^{-1}	26	24.49		09.798(4)	1.719	3.080
	300µlL^{-1}	32	30.61		09.487(4)	2.122	3.877
	350µlL^{-1}	42	40.82	398	12.649(4)	3.122	4.877
	400µlL^{-1}	52	51.02		11.180(4)	3.758	6.241
	450µlL^{-1}	58	57.14		14.000(4)	4.489	6.710
	Control	2					
Peppermint oil	200µlL^{-1}	8	4.17		01.000(4)	0.710	1.510
	250µlL^{-1}	16	12.50		02.449(4)	0.160	2.560
	300µlL^{-1}	22	18.75		04.811(4)	0.761	2.838
	350µlL^{-1}	34	31.25	442	09.487(4)	2.122	3.877
	400µlL^{-1}	40	37.50		07.060(4)	2.184	5.015
	450µlL^{-1}	54	52.08		15.811(4)	4.122	5.877
	Control	4					
Camphor oil	200µlL^{-1}	8	6.12		02.449(4)	0.080	1.280
	250µlL^{-1}	12	10.20		01.000(4)	0.710	1.510
	300µlL^{-1}	22	20.41		06.325(4)	1.122	2.877
	350µlL^{-1}	24	22.45	444	05.880(4)	1.161	3.238
	400µlL^{-1}	42	40.82		12.649(4)	3.122	4.877
	450µlL^{-1}	52	51.02		15.811(4)	4.122	5.877
	Control	2					

Essential oils	Concs %	% Mortality	% Corrected mortality	LC_{50} %	t (df)*	95% Confidence limit	
						Lower	Upper
Lemongrass oil	200µlL^{-1}	4	0.00		02.449(4)	0.080	1.280
	250µlL^{-1}	8	4.17		01.633(4)	0.280	1.080
	300µlL^{-1}	14	10.42		02.236(4)	0.241	2.241
	350µlL^{-1}	18	14.58	Nil	05.715(4)	0.719	2.080
	400µlL^{-1}	36	33.33		05.488(4)	1.581	4.818
	450µlL^{-1}	46	43.75		06.322(4)	2.358	6.041
	Control	4					
Bitter orange oil	200µlL^{-1}	2	0.00		01.000(4)	0.710	1.510
	250µlL^{-1}	6	4.08		01.633(4)	0.280	1.080
	300µlL^{-1}	12	10.20		02.236(4)	0.241	2.241
	350µlL^{-1}	16	14.29	Nil	02.746(4)	0.157	2.815
	400µlL^{-1}	34	32.65		08.552(4)	2.161	4.238
	450µlL^{-1}	44	42.86		11.225(4)	3.161	5.238
	Control	2					

LC_{50}=lethal concentration that kill 50% of the exposed larvae; 50 larvae (5 replicates of 10 each) were treated at ecah dose; *Significant at $P<0.05$.

Table 9. Mortality of *C. cephalonica* exposed to different essential oils via fumigant application

Essential oils	Concs.	Mean ± SE at 24 hrs
Eucalyptus + Cedarwood	200µlL^{-1}	2.2 ± 0.734
	250µlL^{-1}	3.8 ± 0.489
	300µlL^{-1}	4.2 ± 0.734
	350µlL^{-1}	5.6 ± 0.678
	400µlL^{-1}	6.6 ± 0.678
	450µlL^{-1}	7.8 ± 0.200
	Control	0.2 ± 0.200
Eucalyptus + Peppermint	200µlL^{-1}	1.8 ± 0.374
	250µlL^{-1}	3.0 ± 0.316
	300µlL^{-1}	3.0 ± 0.400
	350µlL^{-1}	4.8 ± 0.489
	400µlL^{-1}	5.6 ± 0.634
	450µlL^{-1}	6.4 ± 0.244
	Control	0.4 ± 0.249
Eucalyptus + Camphor	200µlL^{-1}	1.6 ± 0.400
	250µlL^{-1}	2.8 ± 0.200
	300µlL^{-1}	3.4 ± 0.244
	350µlL^{-1}	4.0 ± 1.000
	400µlL^{-1}	5.6 ± 0.244
	450µlL^{-1}	6.0 ± 0.316
	Control	0.2 ± 0.200
Eucalyptus + Lemongrass	200µlL^{-1}	1.4 ± 0.244
	250µlL^{-1}	2.4 ± 0.249
	300µlL^{-1}	2.8 ± 0.583
	350µlL^{-1}	3.8 ± 0.489
	400µlL^{-1}	4.6 ± 0.678
	450µlL^{-1}	5.8 ± 0.374
	Control	0.2 ± 0.200
Eucalyptus + Bitter orange	200µlL^{-1}	1.2 ± 0.200
	250µlL^{-1}	1.6 ± 0.400
	300µlL^{-1}	2.8 ± 0.489
	350µlL^{-1}	3.6 ± 0.244
	400µlL^{-1}	4.6 ± 0.249
	450µlL^{-1}	5.6 ± 0.249
	Control	0.2 ± 0.200
Peppermint + Bitter orange	200µlL^{-1}	0.8 ± 0.200
	250µlL^{-1}	1.2 ± 0.200
	300µlL^{-1}	2.2 ± 0.200
	350µlL^{-1}	2.4 ± 0.244
	400µlL^{-1}	4.2 ± 0.374
	450µlL^{-1}	5.2 ± 0.374
	Control	0.4 ± 0.244

Essential oils	Concs.	Mean ± SE at 24 hrs
Camphor + Lemongrass	200µlL^{-1}	0.6 ± 0.244
	250µlL^{-1}	1.0 ± 0.316
	300µlL^{-1}	2.0 ± 0.316
	350µlL^{-1}	2.2 ± 0.374
	400µlL^{-1}	4.0 ± 0.316
	450µlL^{-1}	5.0 ± 0.316
	Control	0.2 ± 0.200
Camphor + Bitter orange	200µlL^{-1}	0.4 ± 0.244
	250µlL^{-1}	0.8 ± 0.374
	300µlL^{-1}	1.8 ± 0.489
	350µlL^{-1}	2.0 ± 0.447
	400µlL^{-1}	3.8 ± 0.200
	450µlL^{-1}	4.8 ± 0.374
	Control	0.2 ± 0.200
Bitter orange + Lemongrass	200µlL^{-1}	0.4 ± 0.244
	250µlL^{-1}	0.8 ± 0.374
	300µlL^{-1}	1.4 ± 0.509
	350µlL^{-1}	1.8 ± 0.489
	400µlL^{-1}	3.6 ± 0.244
	450µlL^{-1}	4.6 ± 0.400
	Control	0.4 ± 0.244
Cedarwood + Peppermint	200µlL^{-1}	1.8 ± 0.200
	250µlL^{-1}	3.4 ± 0.244
	300µlL^{-1}	3.8 ± 0.489
	350µlL^{-1}	4.8 ± 0.374
	400µlL^{-1}	5.8 ± 0.489
	450µlL^{-1}	6.8 ± 0.489
	Control	0.2 ± 0.200
Cedarwood + Camphor	200µlL^{-1}	1.6 ± 0.244
	250µlL^{-1}	3.2 ± 0.200
	300µlL^{-1}	3.6 ± 0.244
	350µlL^{-1}	4.6 ± 0.244
	400µlL^{-1}	5.6 ± 0.244
	450µlL^{-1}	6.6 ± 0.244
	Control	0.2 ± 0.200
Cedarwood + Lemongrass	200µlL^{-1}	1.4 ± 0.400
	250µlL^{-1}	2.8 ± 0.200
	300µlL^{-1}	3.4 ± 0.244
	350µlL^{-1}	4.4 ± 0.244
	400µlL^{-1}	5.4 ± 0.400
	450µlL^{-1}	6.0 ± 0.316
	Control	4.0 ± 0.244

Essential oils	Concs.	Mean ± SE at 24 hrs
Cedarwood + Bitter orange	200µlL^{-1}	1.2 ± 0.200
	250µlL^{-1}	2.6 ± 0.244
	300µlL^{-1}	3.2 ± 0.200
	350µlL^{-1}	3.8 ± 0.374
	400µlL^{-1}	5.0 ± 0.447
	450µlL^{-1}	5.8 ± 0.374
	Control	0.2 ± 0.200
Camphor + Peppermint	200µlL^{-1}	1.0 ± 0.316
	250µlL^{-1}	2.0 ± 0.447
	300µlL^{-1}	2.6 ± 0.400
	350µlL^{-1}	3.6 ± 0.244
	400µlL^{-1}	4.2 ± 0.489
	450µlL^{-1}	5.6 ± 0.244
	Control	0.2 ± 0.200
Peppermint + Lemongrass	200µlL^{-1}	1.0 ± 0.000
	250µlL^{-1}	1.4 ± 0.244
	300µlL^{-1}	2.4 ± 0.244
	350µlL^{-1}	2.6 ± 0.244
	400µlL^{-1}	4.4 ± 0.244
	450µlL^{-1}	5.4 ± 0.509
	Control	0.2 ± 0.200

Mean of 5 replicates each containing 10 larvae

Table 10. Insecticidal activity of essential oils against *Corcyra cephalonica* at different concentrations via contact application

Essential oils	Concs.	% Mortality	% Corrected mortality	LC_{50}	t (df)*	95% Confidence Limit	
						Lower	Upper
Eucalyptus + Cedarwood	200µlL^{-1}	22	20.41		06.325(4)	1.122	2.877
	250µlL^{-1}	38	36.73		09.000(4)	2.489	4.710
	300µlL^{-1}	42	40.82		04.781(4)	1.677	6.322
	350µlL^{-1}	56	55.10	328	07.962(4)	3.516	7.283
	400µlL^{-1}	66	65.31		10.667(4)	4.734	8.065
	450µlL^{-1}	78	77.55		31.027(4)	6.919	8.280
	Control	2					
Eucalyptus + Peppermint	200µlL^{-1}	18	14.58		05.715(4)	0.719	2.080
	250µlL^{-1}	30	27.08		10.614(4)	1.919	3.280
	300µlL^{-1}	36	33.33		16.000(4)	2.644	3.755
	350µlL^{-1}	48	45.83	378	17.963(4)	3.719	5.080
	400µlL^{-1}	56	54.17		07.076(4)	3.159	7.240
	450µlL^{-1}	64	62.50		18.974(4)	5.122	6.877
	Control	4					
Eucalyptus +Camphor	200µlL^{-1}	16	14.29		05.715(4)	0.719	2.080
	250µlL^{-1}	28	26.53		10.614(4)	1.919	3.280
	300µlL^{-1}	34	32.65		16.000(4)	2.644	3.755
	350µlL^{-1}	40	38.78	392	10.156(4)	2.761	4.838
	400µlL^{-1}	56	55.10		22.045(4)	4.719	6.080
	450µlL^{-1}	60	59.18		29.000(4)	5.244	6.355
	Control	2					

Essential oils	Concs.	% Mortality	% Corrected mortality	LC_{50}	t (df)*	95% Confidence Limit	
						Lower	Upper
Eucalyptus + Lemongrass	200µlL^{-1}	14	12.24		06.000(4)	0.644	1.755
	250µlL^{-1}	24	22.45		05.880(4)	1.161	3.238
	300µlL^{-1}	28	26.53		04.333(4)	0.934	4.265
	350µlL^{-1}	38	36.73	420	06.000(4)	1.934	5.265
	400µlL^{-1}	46	44.90		07.333(4)	2.734	6.065
	450µlL^{-1}	58	57.14		22.862(4)	4.919	6.280
	Control	2					
Eucalyptus + Bitter orange	200µlL^{-1}	12	10.20		07.333(4)	2.734	6.280
	250µlL^{-1}	16	14.29		05.715(4)	0.719	2.080
	300µlL^{-1}	28	26.53		06.500(4)	1.489	3.710
	350µlL^{-1}	36	34.69	424	13.880(4)	2.719	4.080
	400µlL^{-1}	46	44.90		17.963(4)	3.719	5.080
	450µlL^{-1}	56	55.10		22.045(4)	4.719	6.080
	Control	2					
Peppermint + Bitter orange	200µlL^{-1}	8	4.17		01.633(4)	0.280	1.080
	250µlL^{-1}	12	8.33		04.000(4)	0.244	1.355
	300µlL^{-1}	22	18.75		09.000(4)	1.244	2.355
	350µlL^{-1}	24	20.83	450	04.333(4)	0.934	4.265
	400µlL^{-1}	42	39.58		06.517(4)	2.181	5.418
	450µlL^{-1}	52	50.00		09.798(4)	3.439	6.160
	Control	4					

Essential oils	Concs.	% Mortality	% Corrected mortality	LC_{50}	t (df)*	95% Confidence Limit	
						Lower	Upper
Camphor + Lemongrass	200µlL^{-1}	6	4.08		01.633(4)	0.280	1.080
	250µlL^{-1}	10	8.16		04.000(4)	0.244	1.355
	300µlL^{-1}	20	18.37		09.000(4)	1.244	2.355
	350µlL^{-1}	22	20.41	Nil	06.325(4)	1.122	2.877
	400µlL^{-1}	40	38.78		07.757(4)	2.439	5.160
	450µlL^{-1}	50	48.98		24.000(4)	4.244	5.352
	Control	2					
Camphor + Bitter orange	200µlL^{-1}	4	2.04		01.000(4)	0.355	0.755
	250µlL^{-1}	8	6.12		02.449(4)	0.800	1.280
	300µlL^{-1}	18	16.33		04.000(4)	0.489	2.710
	350µlL^{-1}	20	18.37	Nil	04.811(4)	0.761	2.838
	400µlL^{-1}	38	36.73		09.000(4)	2.489	4.710
	450µlL^{-1}	48	46.94		18.779(4)	0.391	5.280
	Control	2					
Bitter orange + Lemongrass	200µlL^{-1}	4	0.00		01.000(4)	0.887	0.877
	250µlL^{-1}	8	4.17	Nil	01.633(4)	0.280	1.080
	300µlL^{-1}	14	10.42		03.162(4)	0.122	1.877
	350µlL^{-1}	18	14.58		05.715(4)	0.719	2.080
	400µlL^{-1}	36	33.33		08.552(4)	2.161	4.238
	450µlL^{-1}	46	43.75		11.225(4)	3.161	5.238
	Control	4					

Essential oils	Concs.	% Mortality	% Corrected mortality	LC_{50}	t (df)*	95% Confidence Limit	
						Lower	Upper
Cedarwood + Peppermint	200µlL^{-1}	18	16.33		06.532(4)	0.919	2.280
	250µlL^{-1}	34	32.65		16.000(4)	2.644	3.755
	300µlL^{-1}	38	36.73		06.000(4)	1.934	5.265
	350µlL^{-1}	48	46.94	362	18.779(4)	3.919	5.280
	400µlL^{-1}	58	57.14		09.333(4)	3.934	7.265
	450µlL^{-1}	68	67.35		11.000(4)	4.934	8.265
	Control	2					
Cedarwood + Camphor	200µlL^{-1}	16	14.29		03.500(4)	0.289	2.510
	250µlL^{-1}	32	30.61		06.000(4)	1.934	5.265
	300µlL^{-1}	36	34.69		13.880(4)	2.719	4.080
	350µlL^{-1}	46	44.90	370	17.963(4)	3.719	5.080
	400µlL^{-1}	56	55.10		22.045(4)	4.719	6.080
	450µlL^{-1}	66	65.31		26.128(4)	5.719	7.080
	Control	2					
Cedarwood + Lemongrass	200µlL^{-1}	14	10.42		03.162(4)	0.122	1.877
	250µlL^{-1}	28	25.00		09.798(4)	1.719	3.080
	300µlL^{-1}	34	31.25		13.880(4)	2.719	4.080
	350µlL^{-1}	44	41.67	394	22.045(4)	4.719	6.080
	400µlL^{-1}	54	52.08		07.906(4)	3.244	6.755
	450µlL^{-1}	60	58.33		10.983(4)	4.184	7.015
	Control	4					

Essential oils	Concs.	% Mortality	% Corrected mortality	LC_{50}	t (df)*	95% Confidence Limit	
						Lower	Upper
Cedarwood + Bitter orange	200µlL^{-1}	12	10.20		13.880(4)	2.719	4.080
	250µlL^{-1}	26	24.49		06.000(4)	1.289	3.510
	300µlL^{-1}	32	30.61		09.487(4)	2.122	3.877
	350µlL^{-1}	38	36.73	410	14.697(4)	2.919	4.280
	400µlL^{-1}	50	48.98		12.829(4)	3.761	5.838
	450µlL^{-1}	58	57.14		22.862(4)	4.919	6.280
	Control	2					
Camphor + Peppermint	200µlL^{-1}	10	8.16		04.000(4)	0.244	1.355
	250µlL^{-1}	20	18.37		03.087(4)	0.181	3.418
	300µlL^{-1}	26	24.49		06.000(4)	1.289	3.510
	350µlL^{-1}	36	34.69	432	13.880(4)	2.719	4.080
	400µlL^{-1}	42	40.82		08.994(4)	2.758	5.241
	450µlL^{-1}	56	55.10		22.045(4)	4.719	6.080
	Control	2					
Peppermint + Lemongrass	200µlL^{-1}	10	8.16		04.000(4)	0.244	1.355
	250µlL^{-1}	14	12.24		06.000(4)	0.644	1.755
	300µlL^{-1}	24	22.45		11.000(4)	1.644	2.755
	350µlL^{-1}	26	24.49	446	09.798(4)	1.719	3.080
	400µlL^{-1}	44	42.86		11.225(4)	3.161	5.238
	450µlL^{-1}	54	53.06		13.898(4)	4.161	6.238
	Control	2					

LC_{50}=lethal concentration that kill 50% of the exposed larvae; 50 larvae (5 replicates of 10 each) were treated at each dose; *Significant at $P<0.05$.

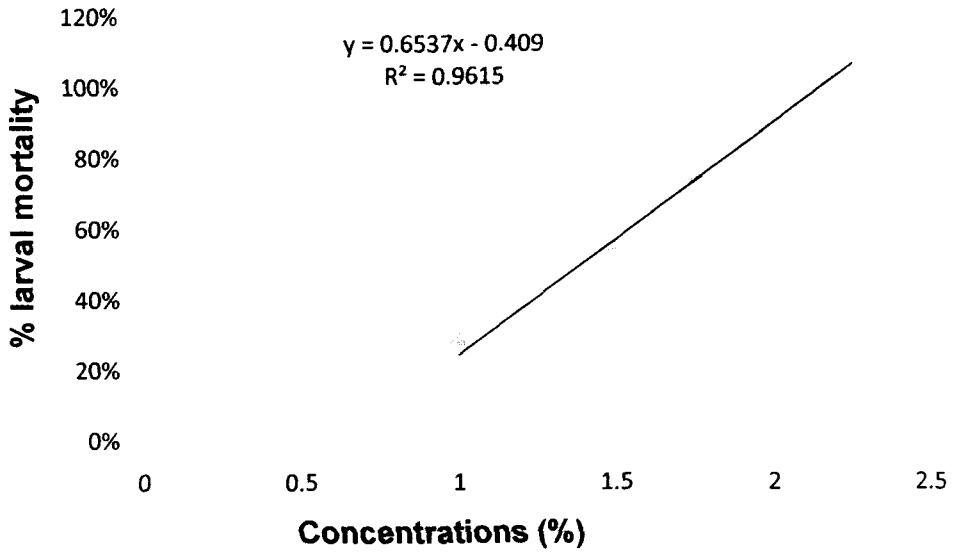


Fig 36. Showing % larval mortality at different concentrations of cedarwood oil on the 4th instar larvae of *Corcyra cephalonica.*

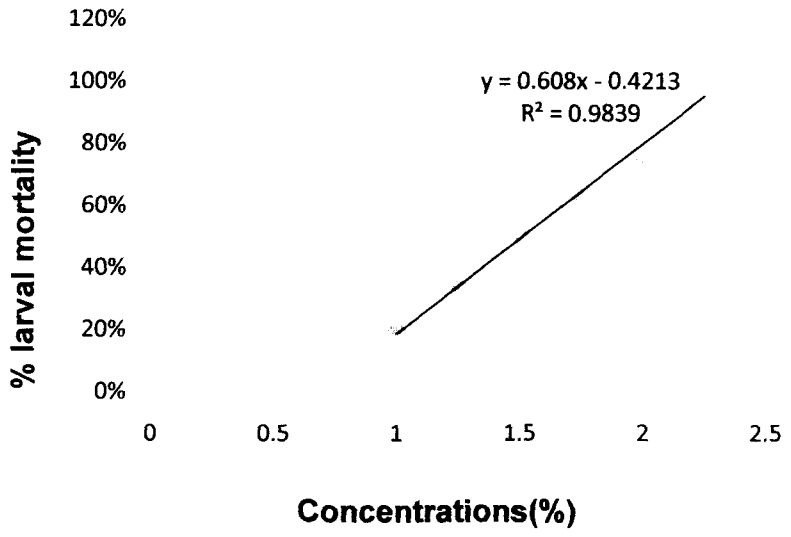


Fig 37. Showing % larval mortality at different concentrations of camphor oil on the 4th instar larvae of *Corcyra cephalonica.*

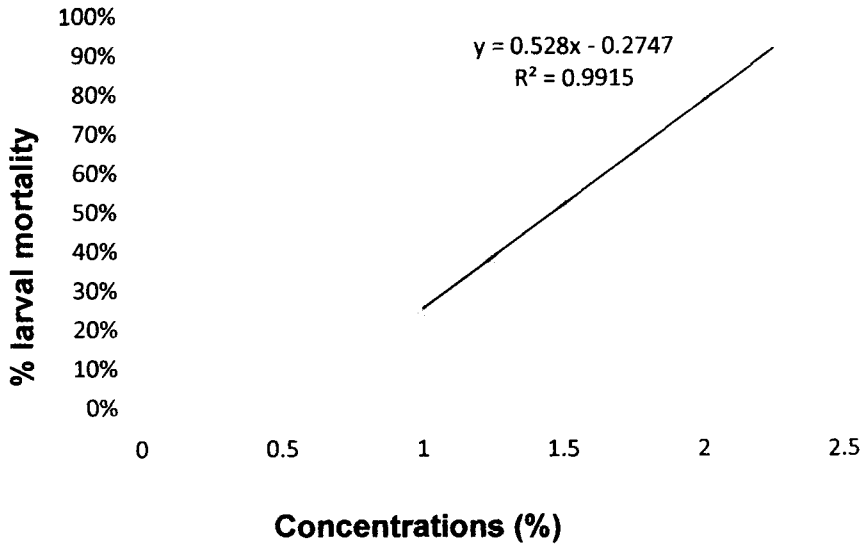


Fig 38. Showing % larval mortality at different concentrations of eucalyptus oil on the 4th instar larvae of *Corcyra cephalonica.*

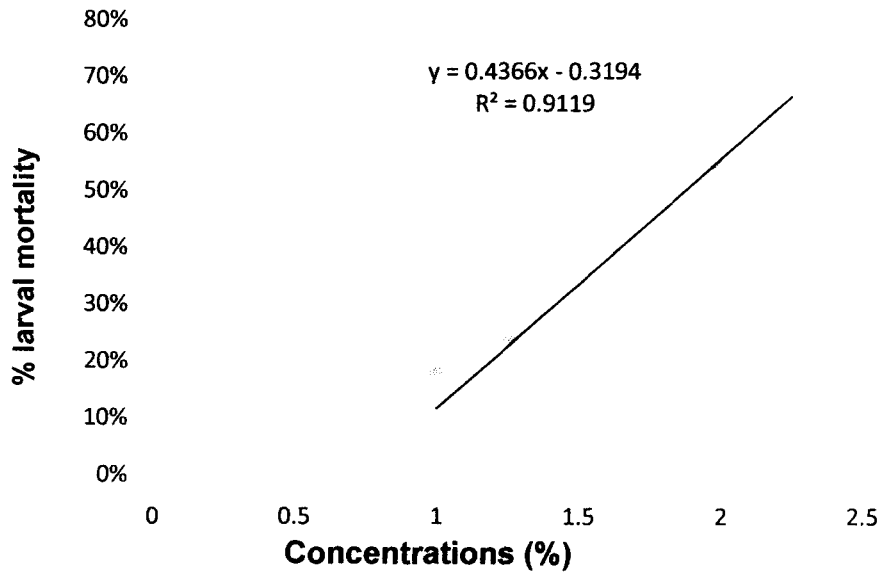


Fig 39. Showing % larval mortality at different concentrations of lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

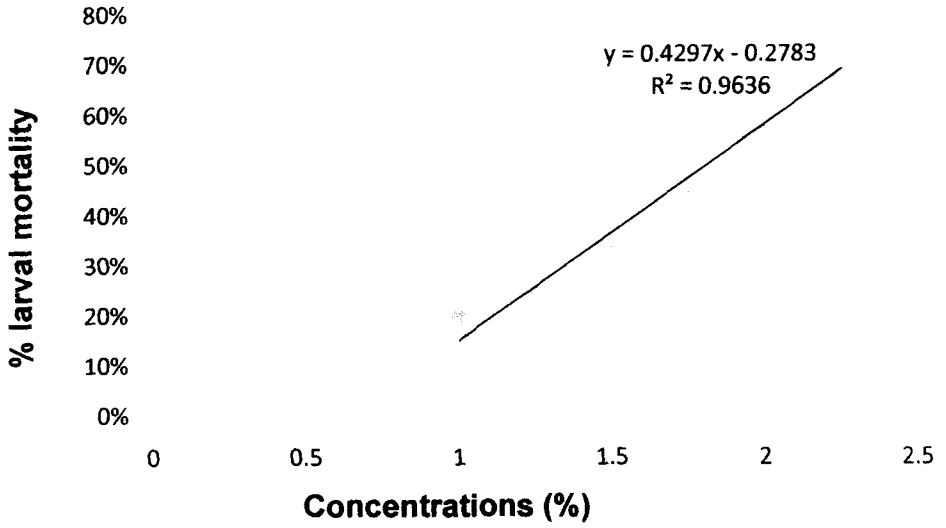


Fig 40. Showing % larval mortality at different concentrations of peppermint oil on the 4th instar larvae of *Corcyra cephalonica.*

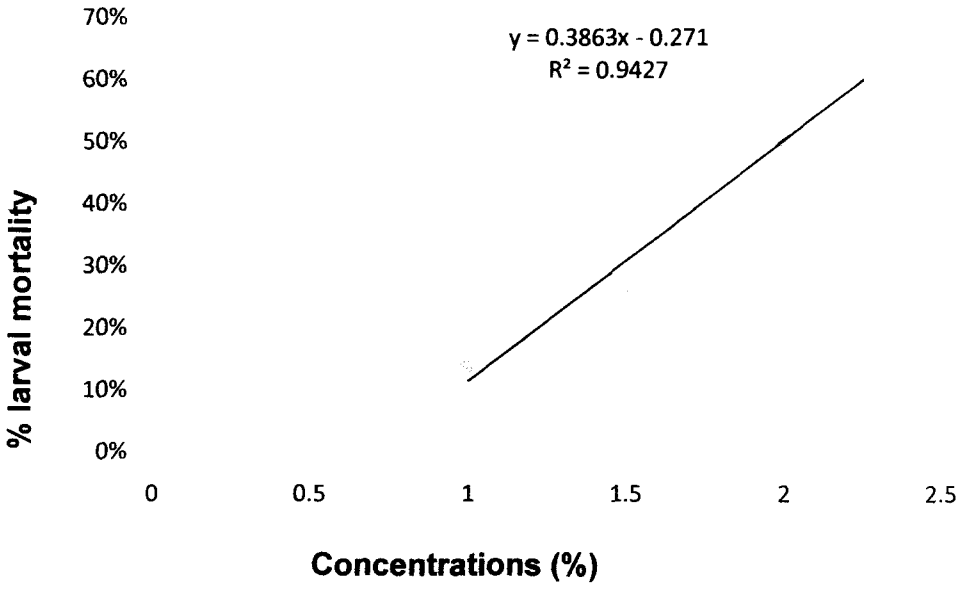


Fig 41. Showing % larval mortality at different concentrations of bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

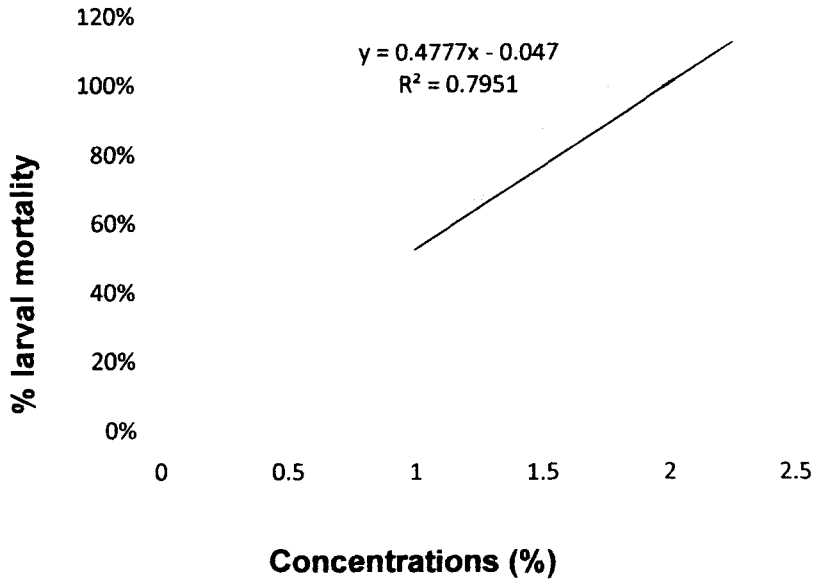


Fig 42. Showing % larval mortality at different concentrations of cedarwood+eucalyptus oil on the 4th instar larvae of *Corcyra cephalonica.*

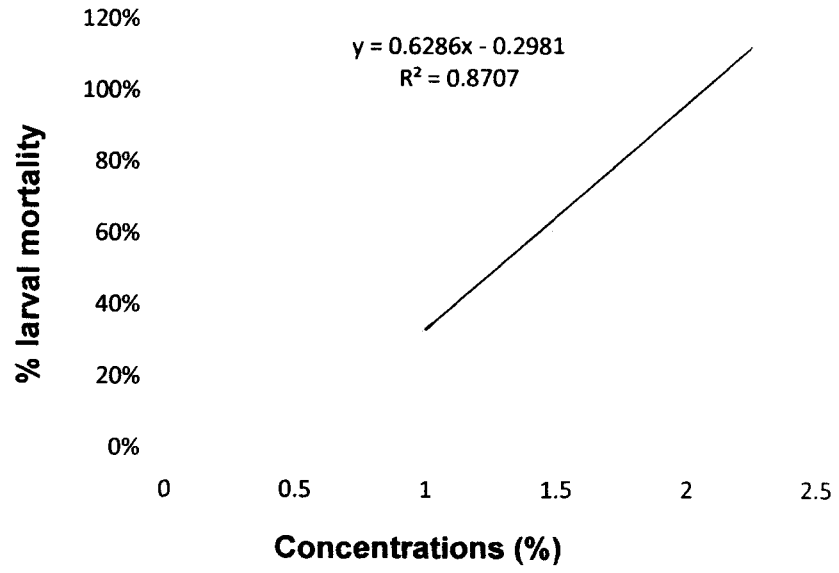


Fig 43. Showing % larval mortality at different concentrations of cedarwood+camphor oil on the 4th instar larvae of *Corcyra cephalonica.*

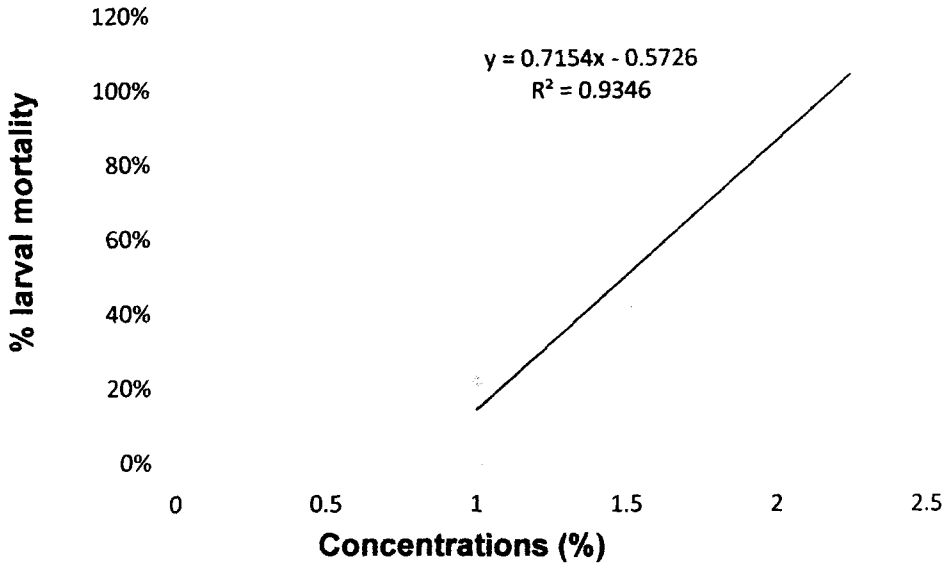


Fig 44. Showing % larval mortality at different concentrations of cedarwood+peppermint oil on the 4th instar larvae of *Corcyra cephalonica.*

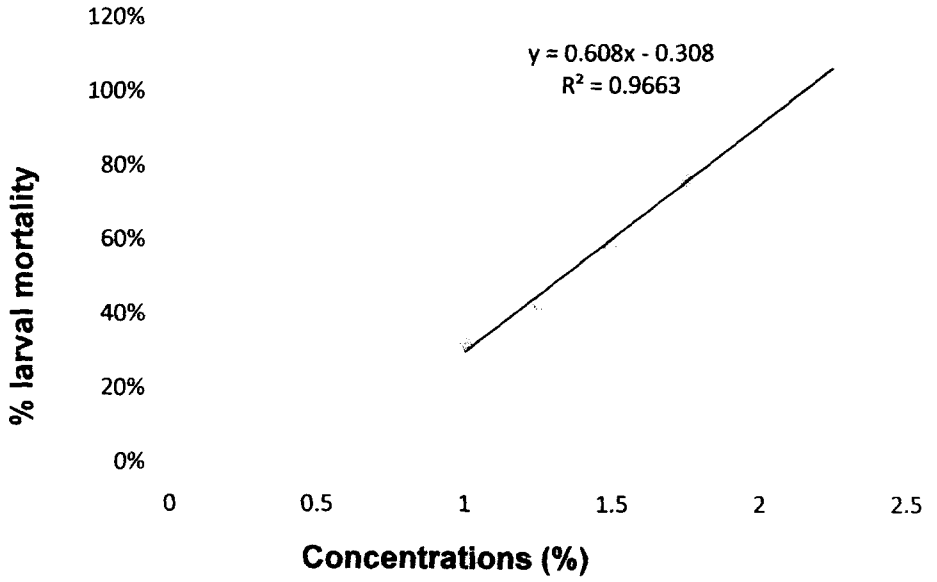


Fig 45. Showing % larval mortality at different concentrations of cedarwood+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

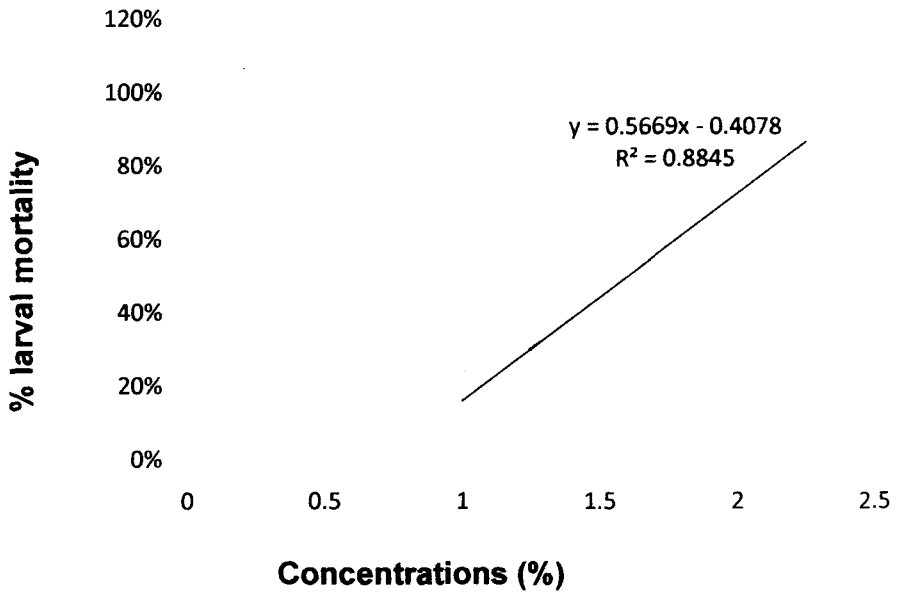


Fig 46. Showing % larval mortality at different concentrations of cedarwood+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

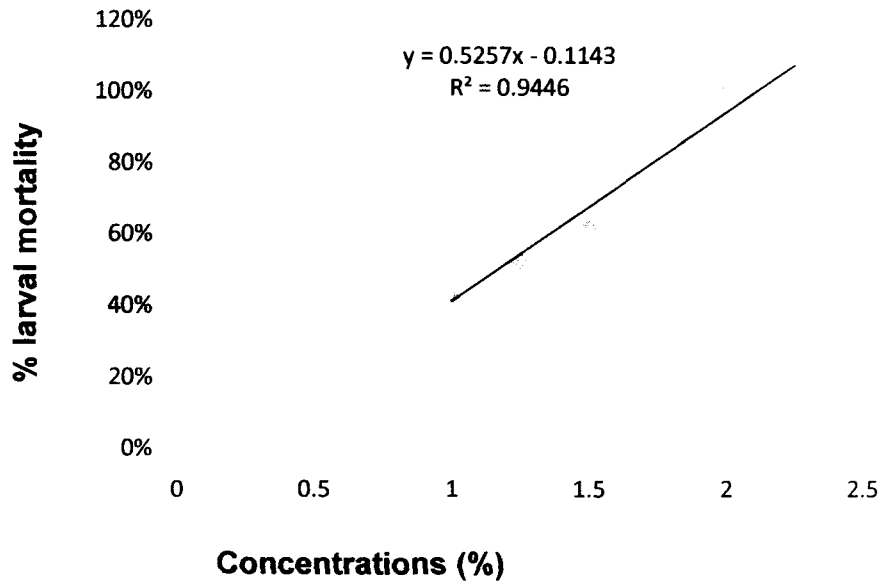


Fig 47. Showing % larval mortality at different concentrations of eucalyptus+camphor oil on the 4th instar larvae of *Corcyra cephalonica.*

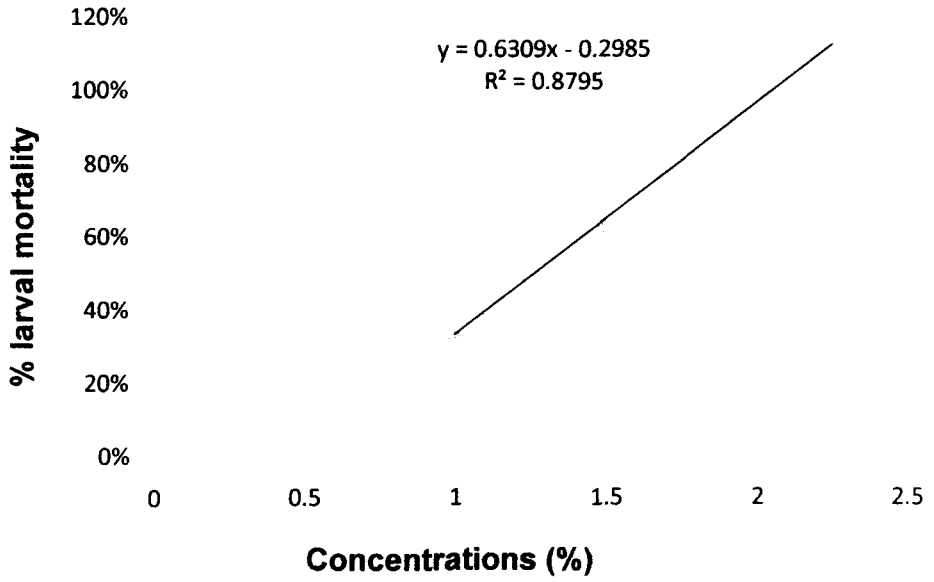


Fig 48. Showing % larval mortality at different concentrations of eucalyptus+peppermint oil on the 4th instar larvae of *Corcyra cephalonica.*

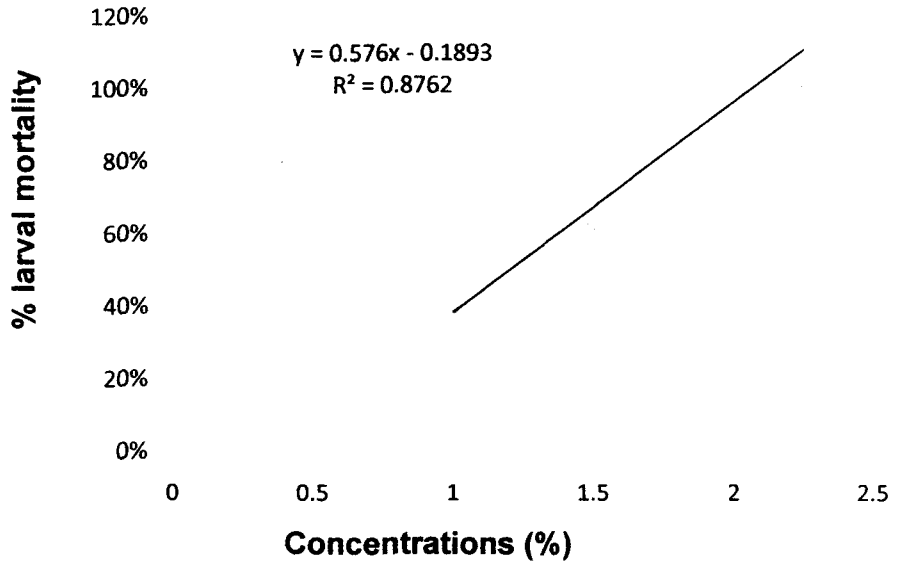


Fig 49. Showing % larval mortality at different concentrations of eucalyptus+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

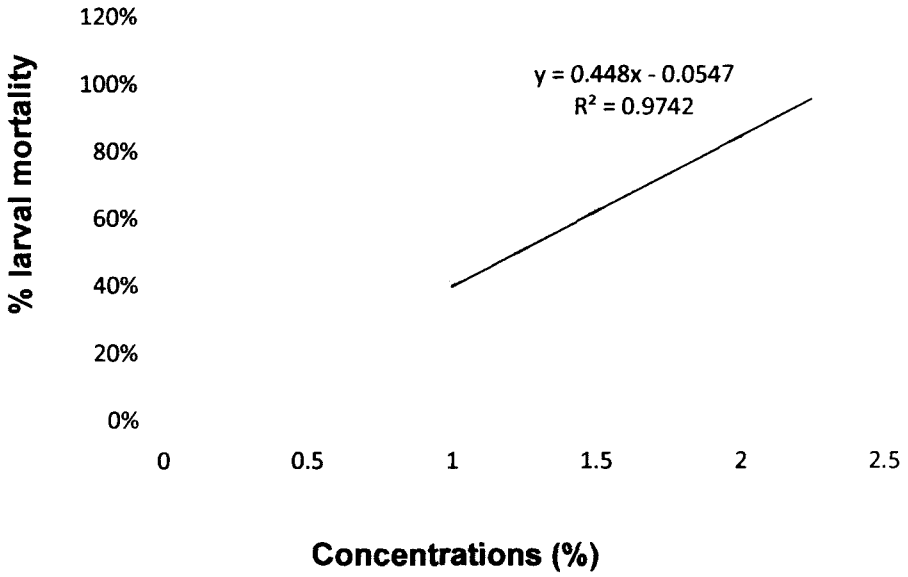


Fig 50. Showing % larval mortality at different concentrations of eucalyptus+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

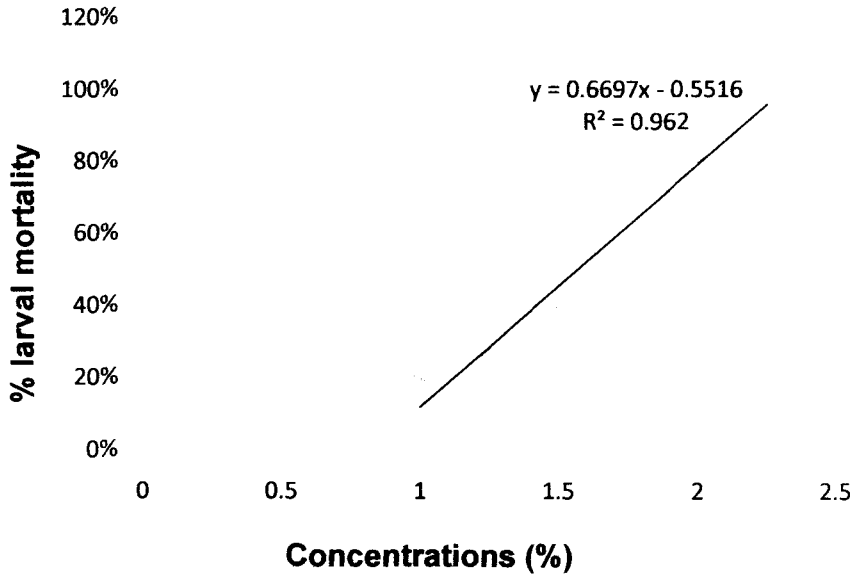


Fig 51. Showing % larval mortality at different concentrations of camphor+peppermint oil on the 4th instar larvae of *Corcyra cephalonica.*

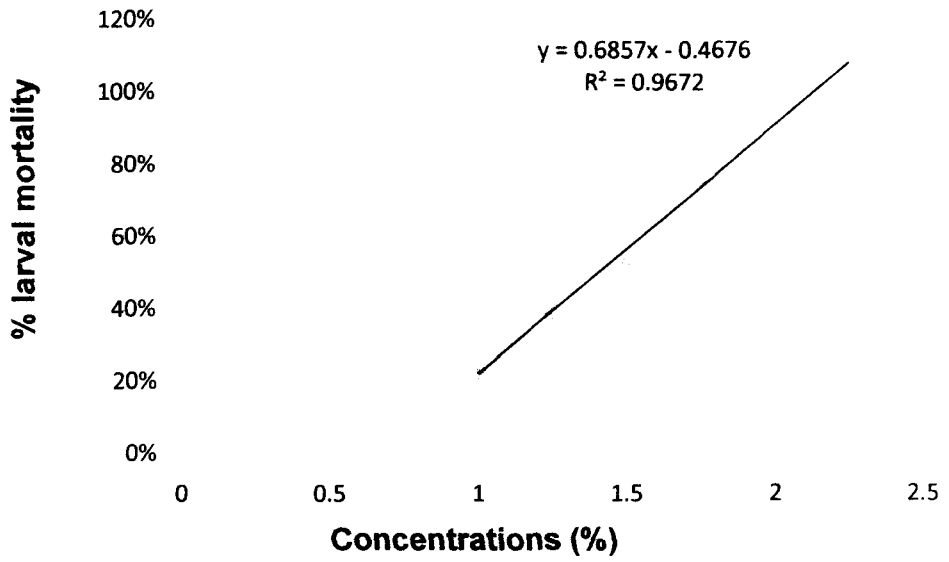


Fig 52. Showing % larval mortality at different concentrations of camphor+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

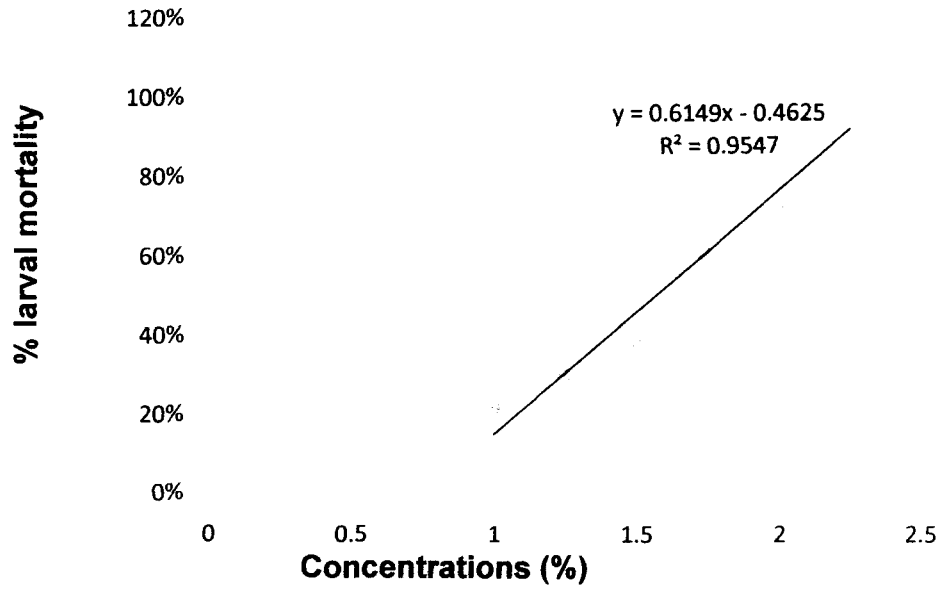


Fig 53. Showing % larval mortality at different concentrations of camphor+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

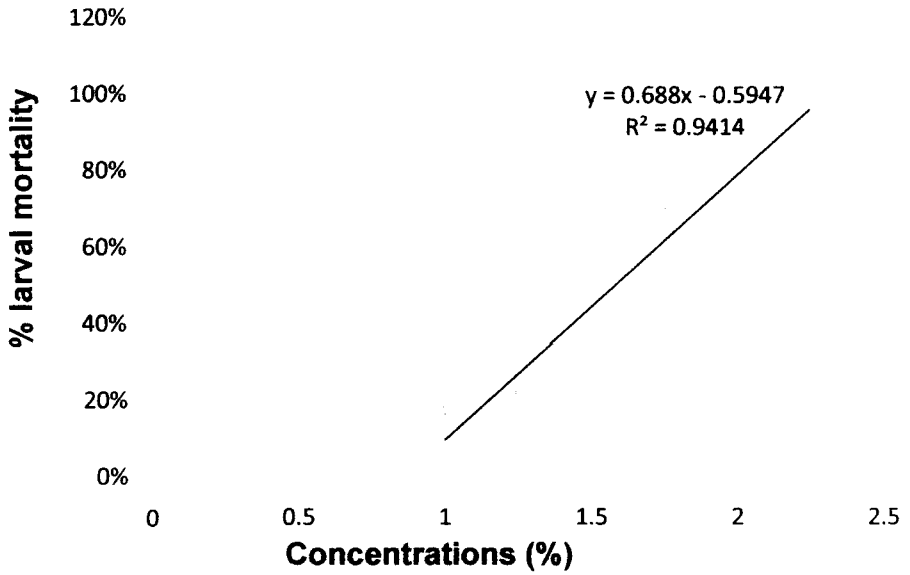


Fig 54. Showing % larval mortality at different concentrations of peppermint+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

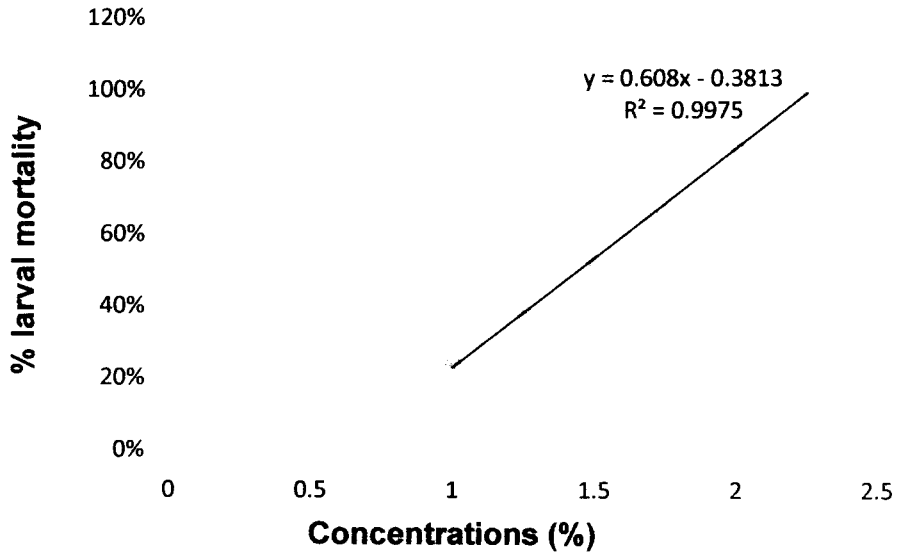


Fig 55. Showing % larval mortality at different concentrations of peppermint+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

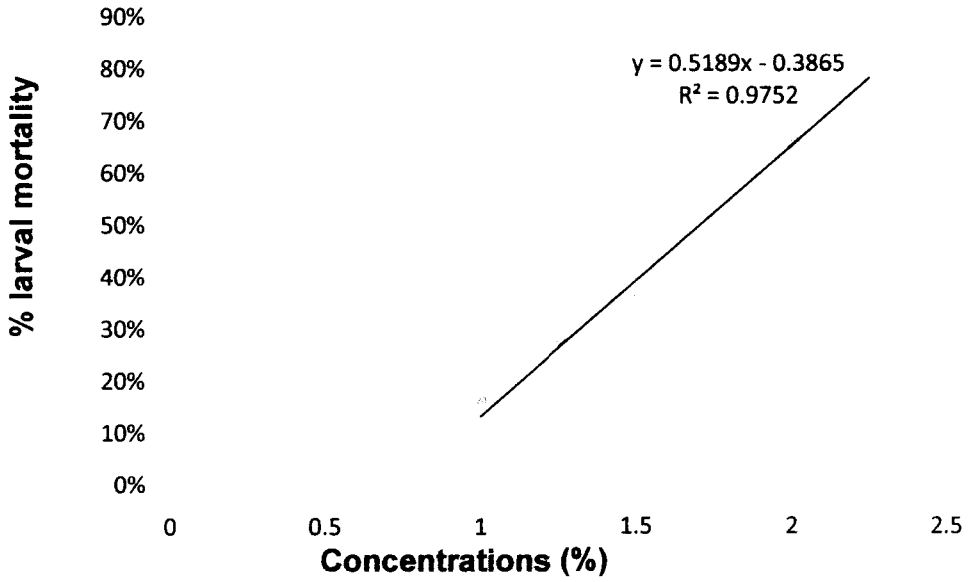


Fig 56. Showing % larval mortality at different concentrations of lemongrass+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

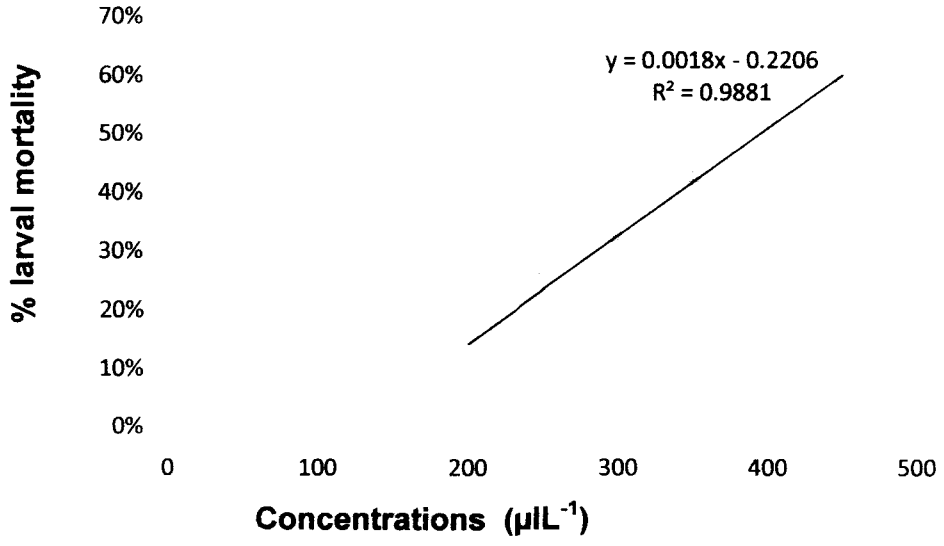


Fig 57. Showing % larval mortality at different concentrations of eucalyptus oil on the 4th instar larvae of *Corcyra cephalonica.*

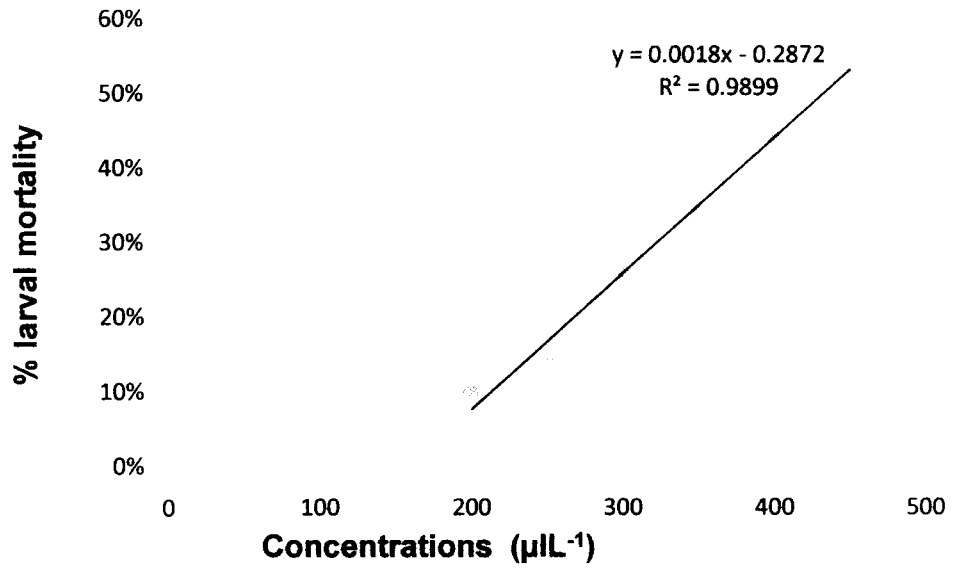


Fig 58. Showing % larval mortality at different concentrations of cedarwood oil on the 4th instar larvae of *Corcyra cephalonica*.

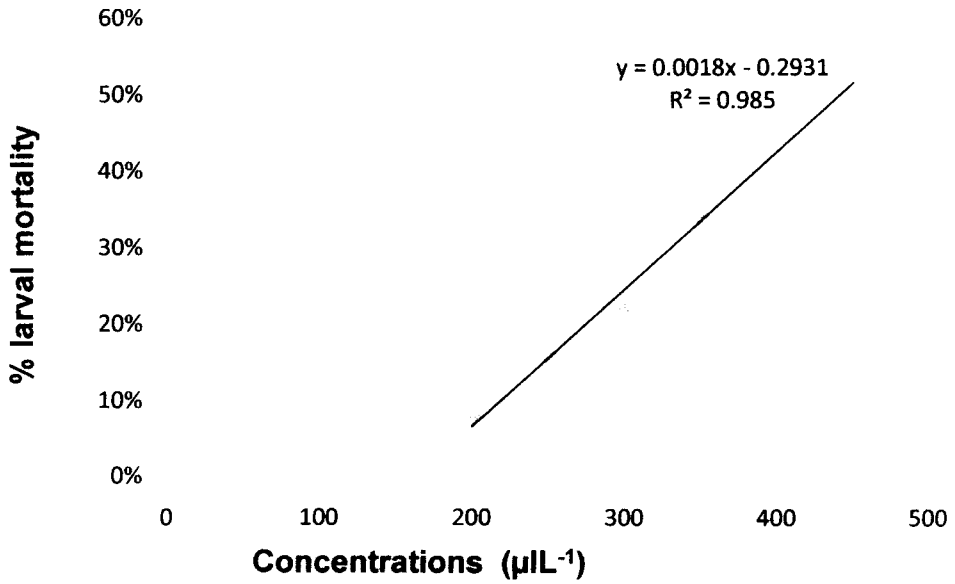


Fig 59. Showing % larval mortality at different concentrations of peppermint oil on the 4th instar larvae of *Corcyra cephalonica*.

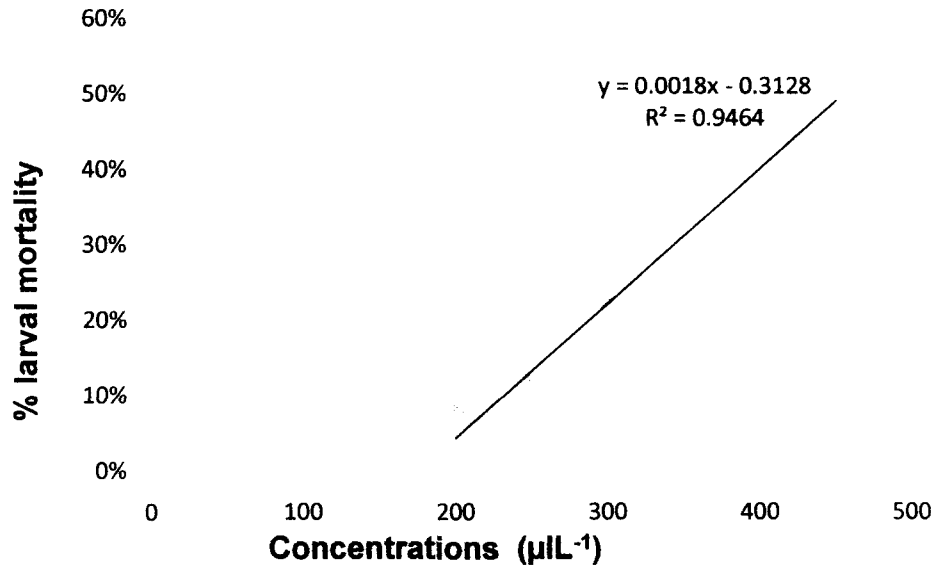


Fig 60. Showing % larval mortality at different concentrations of camphor oil on the 4th instar larvae of *Corcyra cephalonica.*

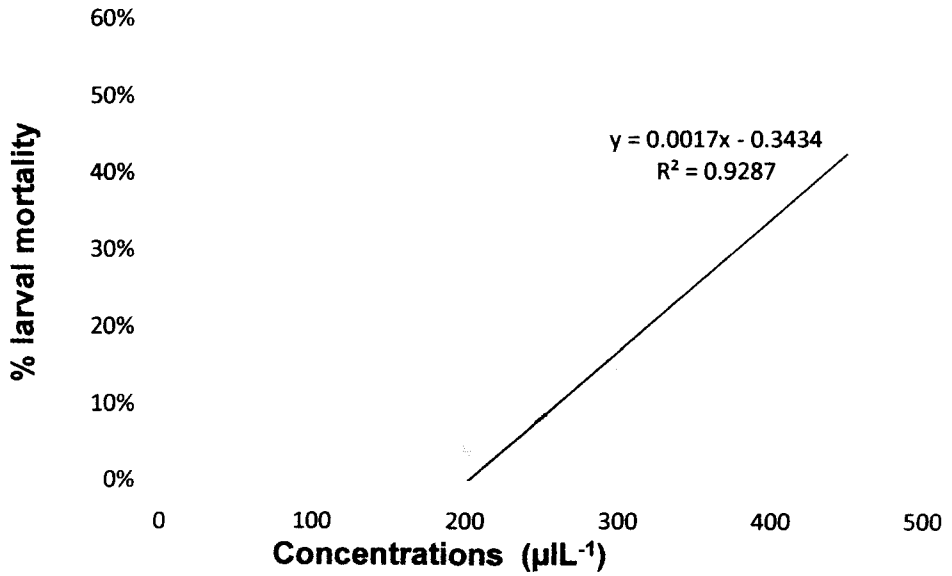


Fig 61. Showing % larval mortality at different concentrations of lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

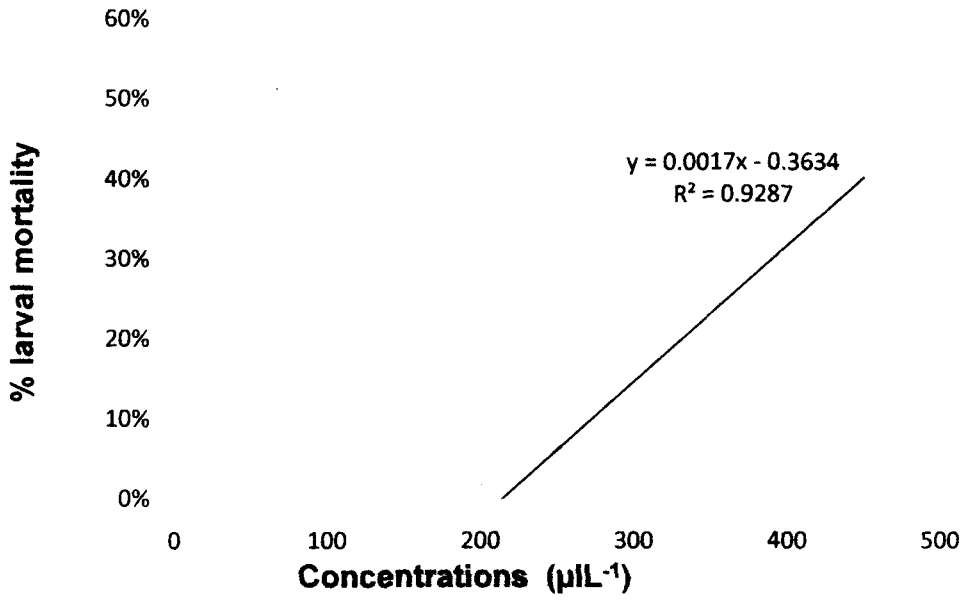


Fig 62. Showing % larval mortality at different concentrations of bitter orange oil on the 4th instar larvae of *Corcyra cephalonica*.

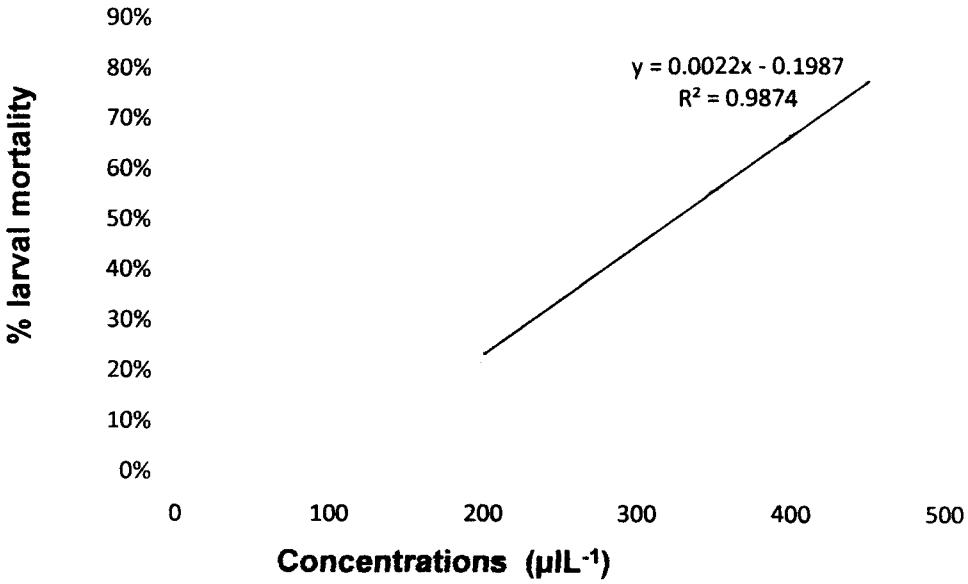


Fig 63. Showing % larval mortality at different concentrations of eucalyptus+cedarwood oil on the 4th instar larvae of *Corcyra cephalonica*.

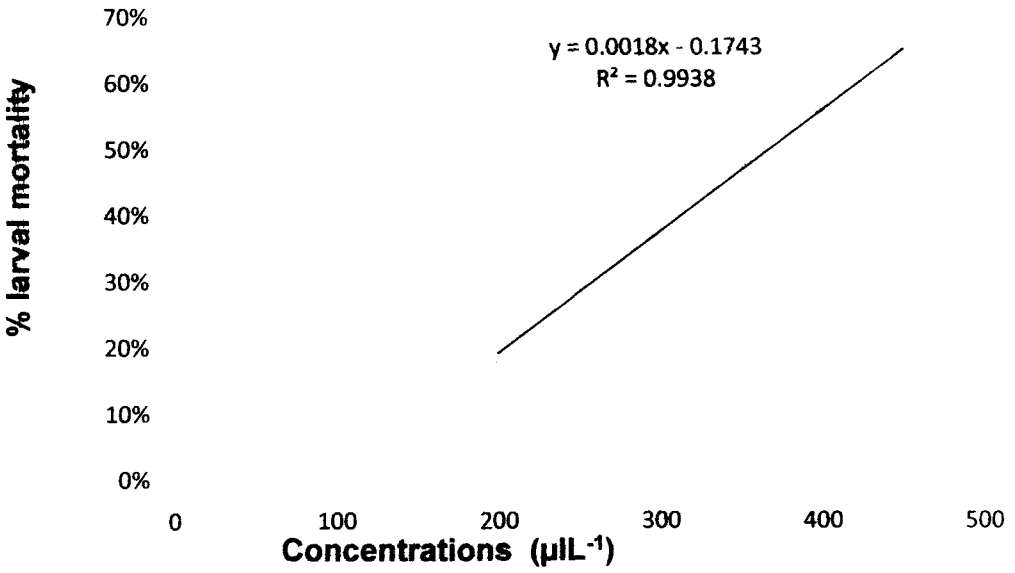


Fig 64. Showing % larval mortality at different concentrations of eucalyptus+peppermint oil on the 4th instar larvae of *Corcyra cephalonica.*

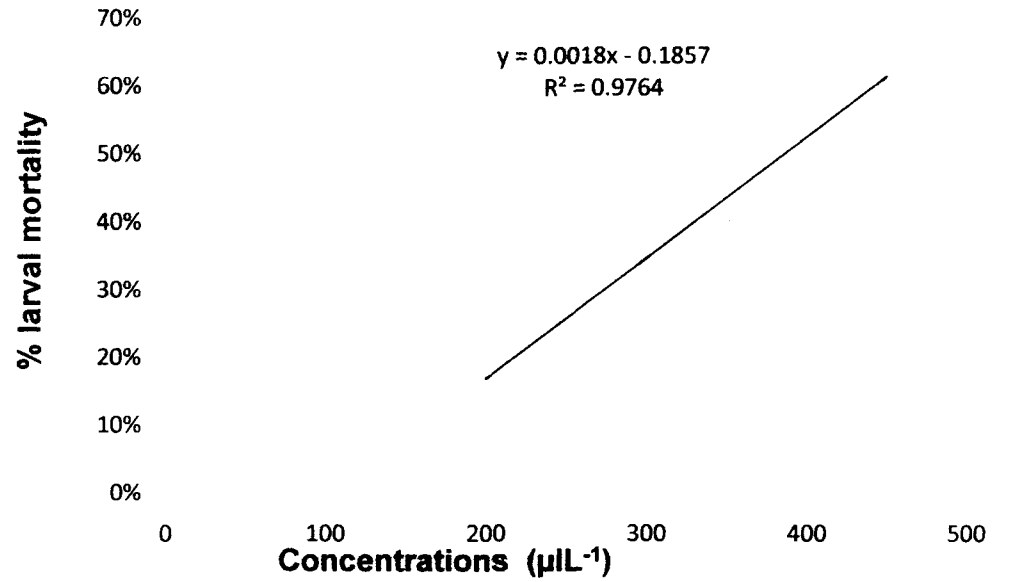


Fig 65. Showing % larval mortality at different concentrations of eucalyptus+camphor oil on the 4th instar larvae of *Corcyra cephalonica.*

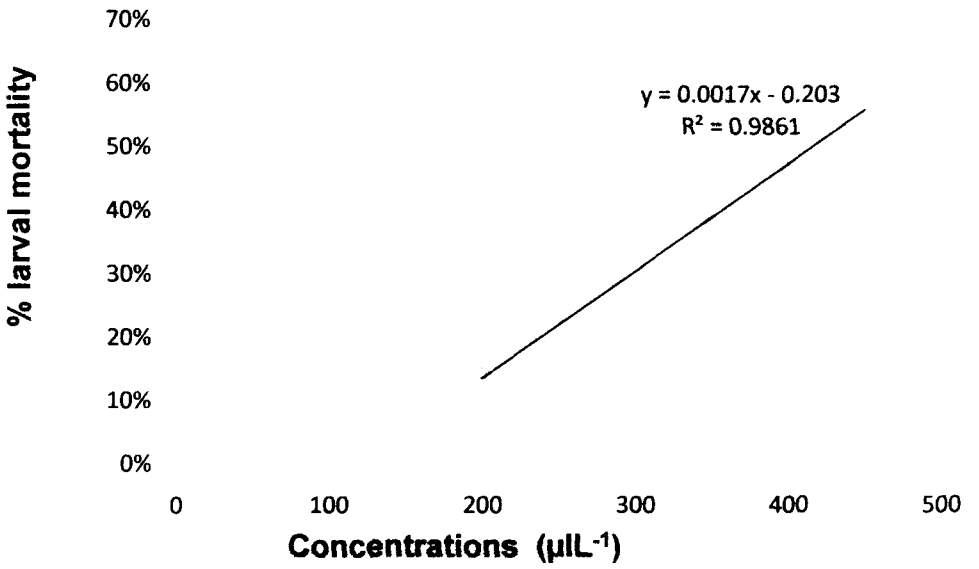


Fig 66. Showing % larval mortality at different concentrations of eucalyptus+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

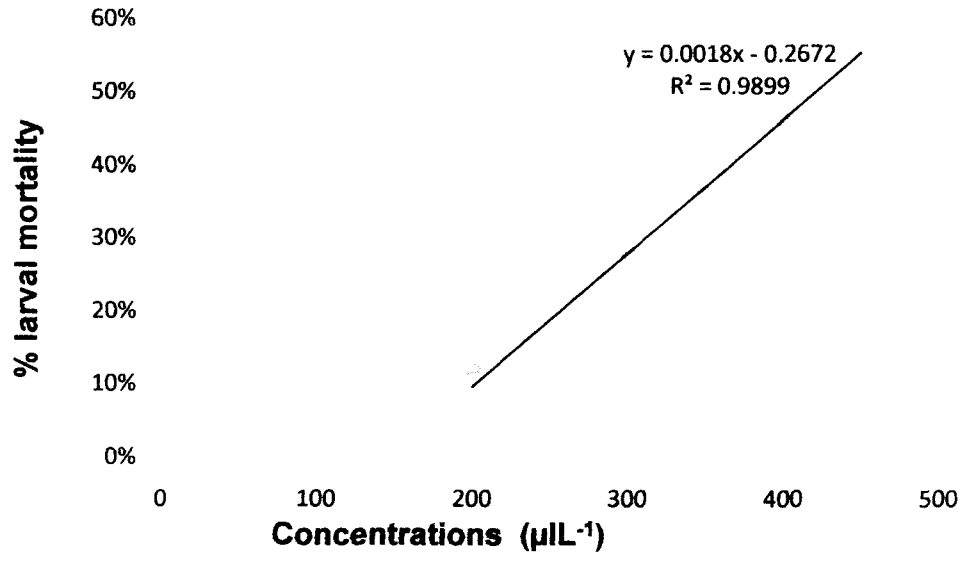


Fig 67. Showing % larval mortality at different concentrations of eucalyptus+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

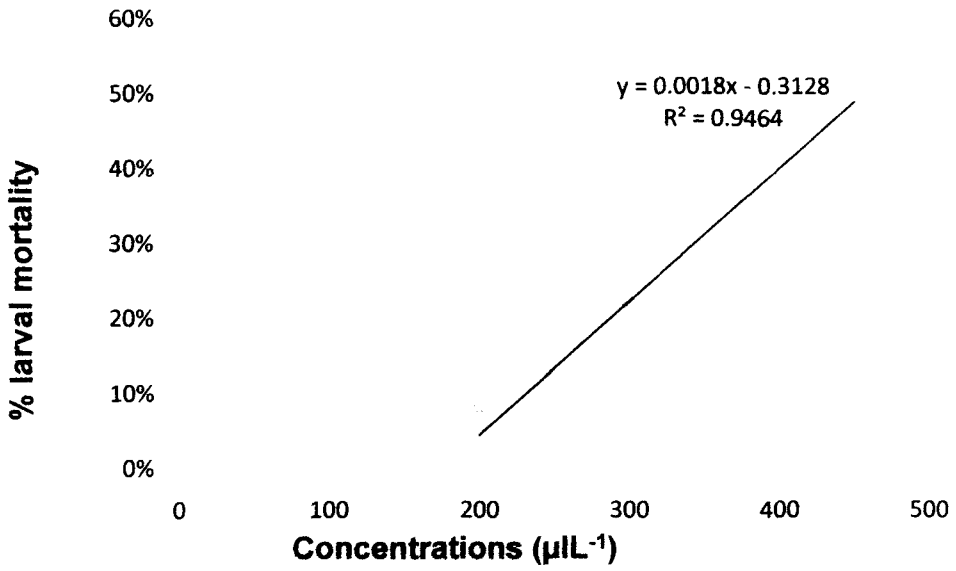


Fig 68. Showing % larval mortality at different concentrations of peppermint+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

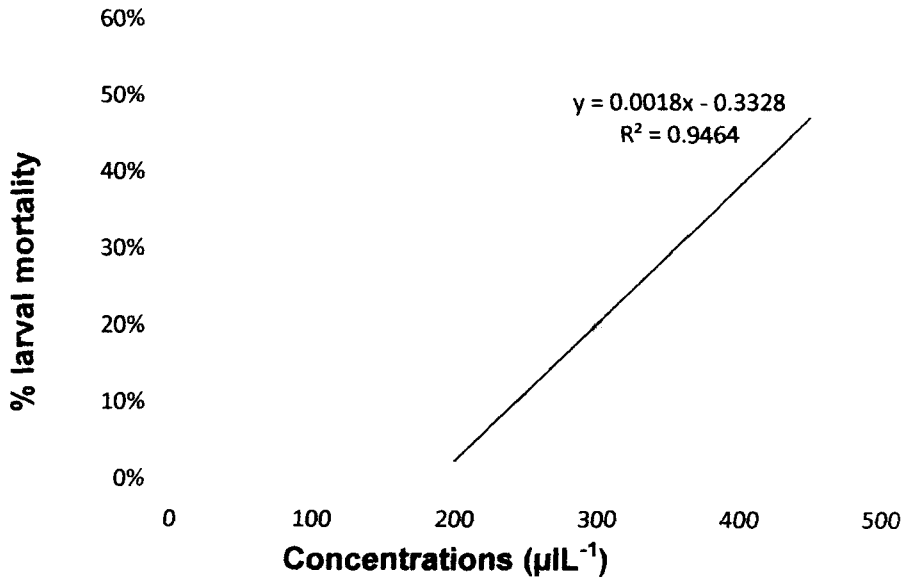


Fig 69. Showing % larval mortality at different concentrations of camphor+lemongrassoil on the 4th instar larvae of *Corcyra cephalonica.*

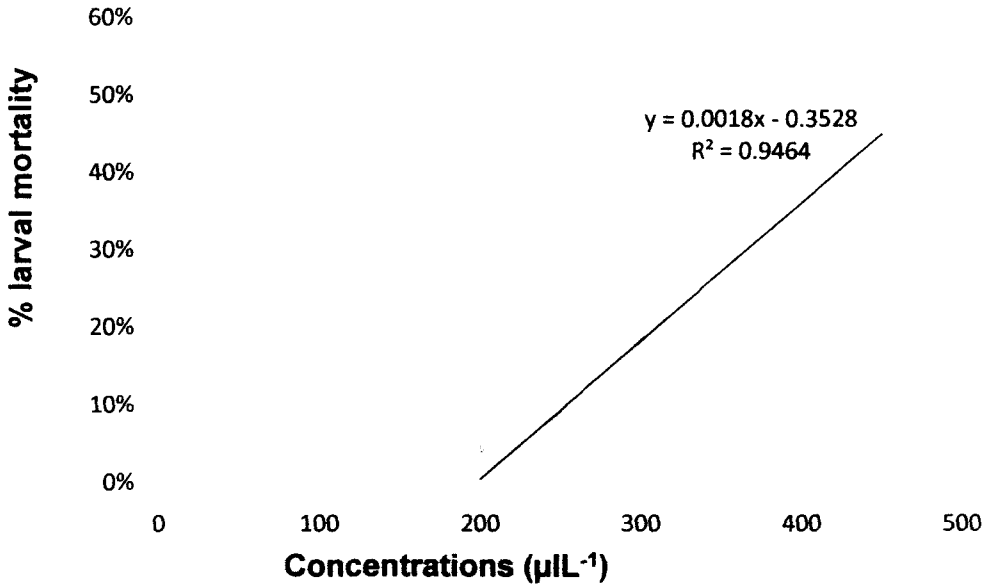


Fig 70. Showing % larval mortality at different concentrations of camphor+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

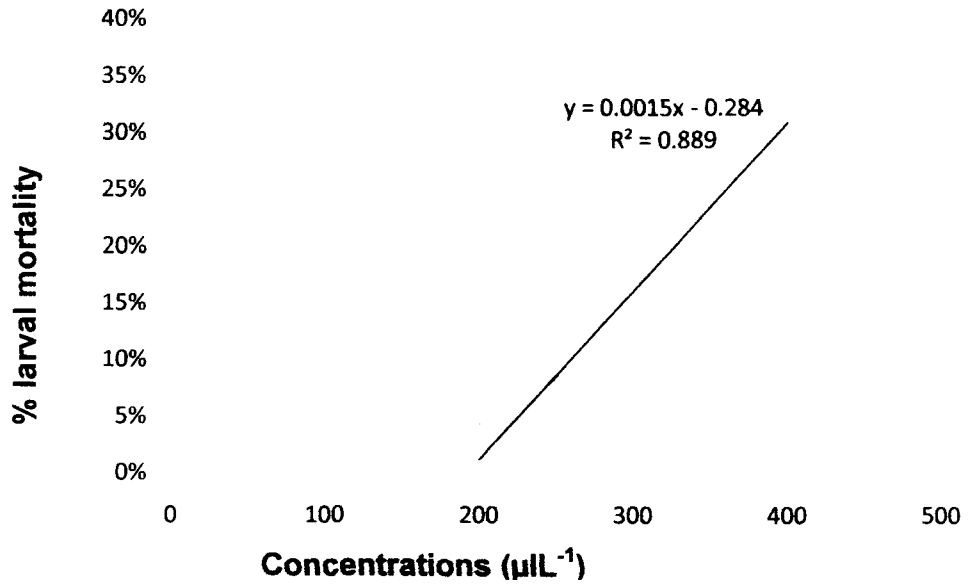


Fig 71. Showing % larval mortality at different concentrations of bitter orange+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

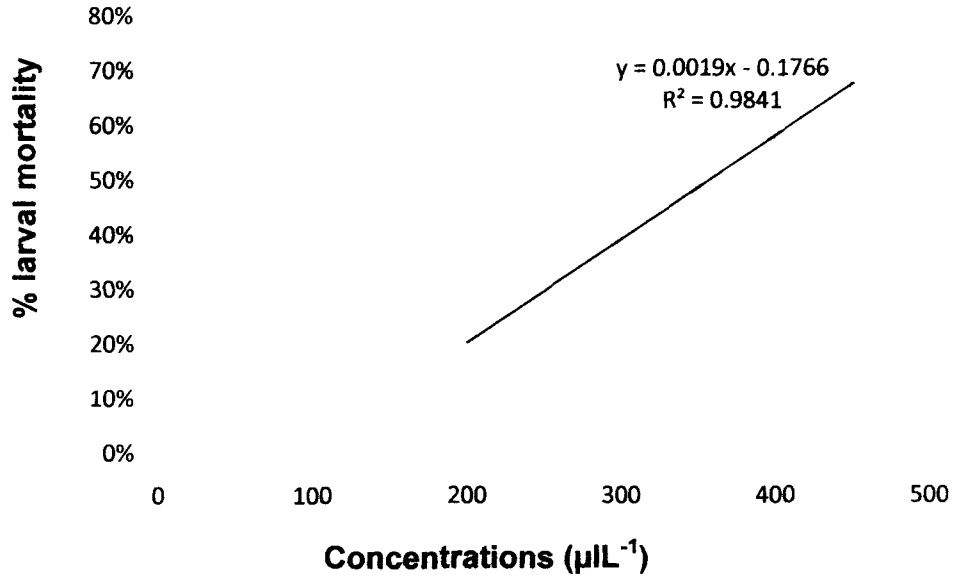


Fig 72. Showing % larval mortality at different concentrations of cedarwood+peppermint oil on the 4th instar larvae of *Corcyra cephalonica.*

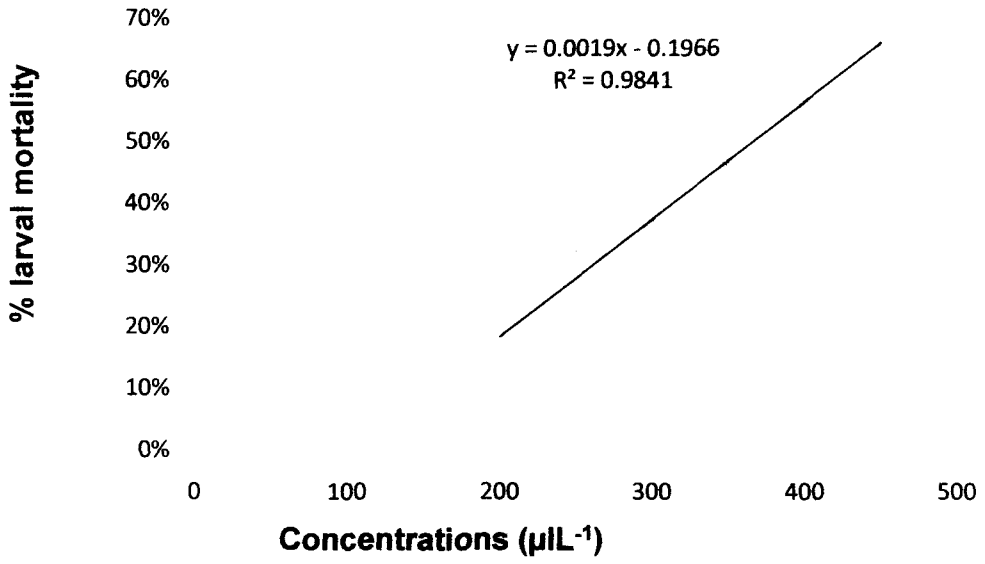


Fig 73. Showing % larval mortality at different concentrations of cedarwood+camphor oil on the 4th instar larvae of *Corcyra cephalonica.*

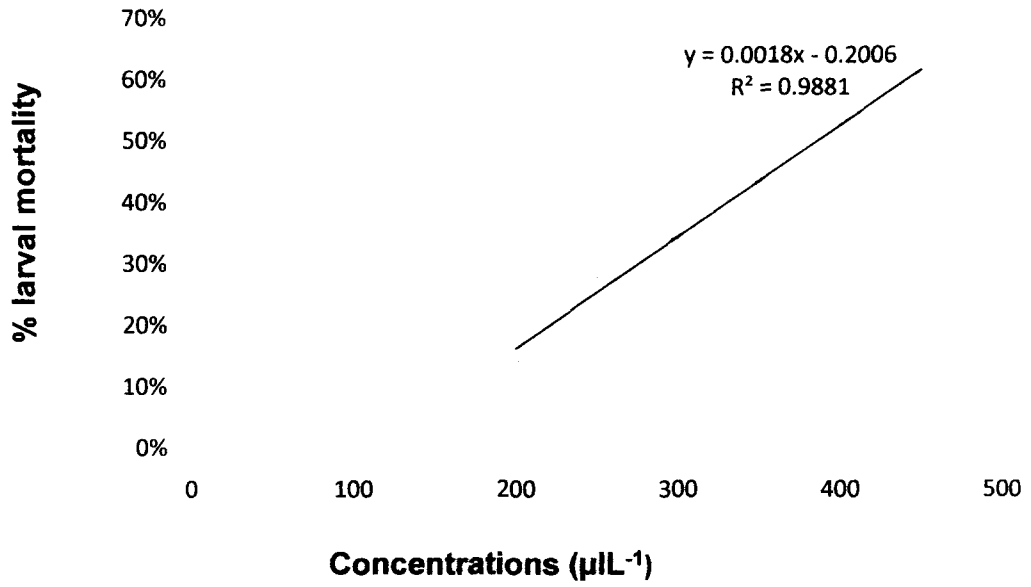


Fig 74. Showing % larval mortality at different concentrations of cedarwood+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica.*

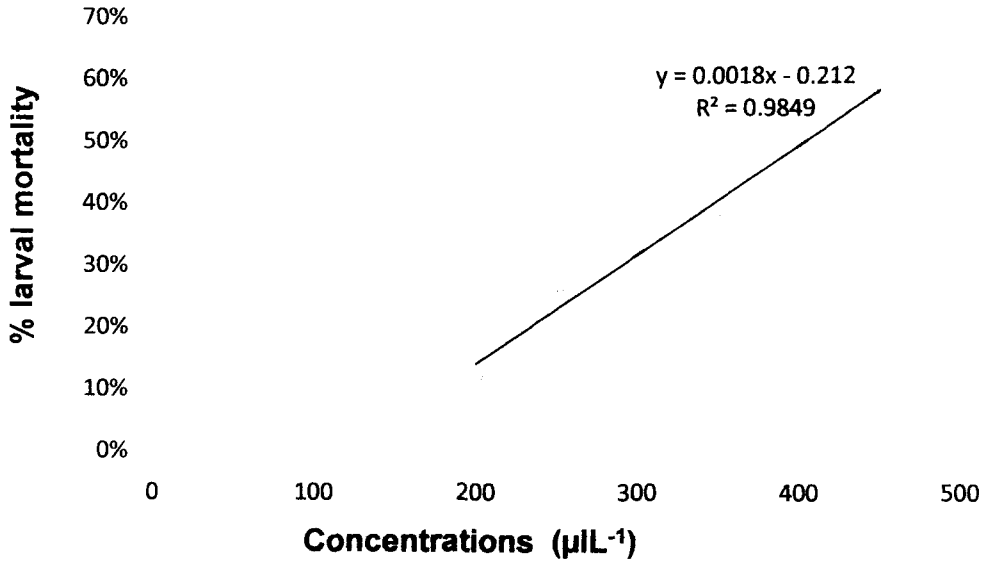


Fig 75. Showing % larval mortality at different concentrations of cedarwood+bitter orange oil on the 4th instar larvae of *Corcyra cephalonica.*

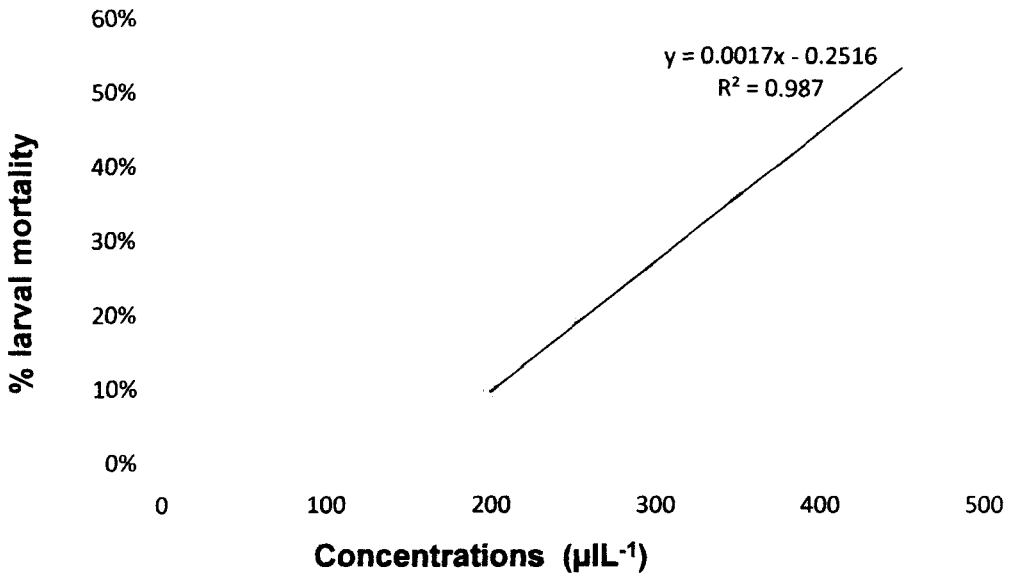


Fig 76. Showing % larval mortality at different concentrations of camphor+peppermint oil on the 4th instar larvae of *Corcyra cephalonica*.

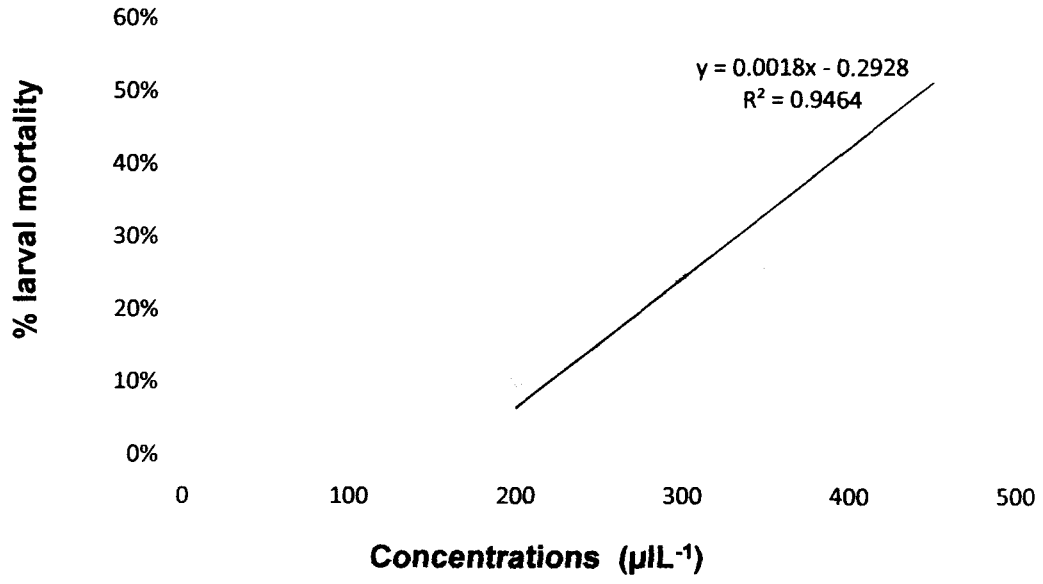


Fig 77. Showing % larval mortality at different concentrations of peppermint+lemongrass oil on the 4th instar larvae of *Corcyra cephalonica*.

Discussion

DISCUSSION

The deleterious effects of conventional insecticides such as organochlorines, organophostphates, carbamates etc. on both health and environment has led to alternative control measures employing non-conventional insecticides. The toxicity of insecticides to humans and wildlife has caused much public concern and promted the use of more target-specific chemicals (Paotelli and Pimental, 2000). The use of natural products can be considered as an important alternative for the control of stored product pest. Many essential oils and their constituents have been studied to possess potential as alternative compounds to currently used insect control agents (Huang *et al.*, 2000; Rajendran and Sriranjini, 2008; Sahaf *et al.*, 2008; Cosimi *et al.*, 2009; Neiro *et al.*, 2009). The results of these studies revealed that there is a wide range of responses and susceptibility with respect to different insect species against a wide range of essential oils. Thus, it becomes inevitable to find out the effective pesticides against particular species of insect pest which do not adversely affect the environment and are also biodegradable.

In the present investigation six essential oils were bio-assayed against *Corcyra cephalonica* via. contact and fumigant applicaition individually and in different combinations. The results showed that insect mortality varied with the essential oil type and concentration. The results from this study indicated that the cedarwood oil exhibited 100% mortality at 2% concentration to *Corcyra cephalonica* in contact bioassay while in fumigant bioassay it showed moderate toxicity. Similar observations of this essential oils on several other insects have been reported. In another study, Incence cedar heartwood was found to be highly toxic to *Ixodes scapularis*, *Xenopsylla cheopis* and *Aedes aegypti* (Dolan *et al.*, 2007). The efficacy of Himalayan cedarwood oil tested against pulse beetle (*Callosobruchus chinensis*), exhibited high knockdown potential, respectively producing 100, 100 and 96% mortality at 3, 2 and 1% concentrations. Gupta *et al.*, (2011) evaluated biopesticidal potential of 6 plant-derived essential oils (*Mentha*

aruensis, *Carum capticum*, *Cymbopogon citrates*, *Eugenia caryophyllata*, *Cedrus deodara* and *Eucalyptus globules*) against *Odontotermes obesus* (termites). It was found that all the termite workers were killed within 30 min at 10% concentration of essential oils. Rahuman *et al.*, (2009) studied the effect of stem bark hot water, acetone, and methanol extracts of *Cedrus deodara* oil on *Culex quinquiefasciatus* and it was found that at 1,000 ppm concentration 100% mortality occurred. Chaudhary *et al.*, (2011), from their study on the cedarwood oil and its fractions against second instar of the diamondback moth, *Plutella xylostella*, have come to the conclusion that this essential oil has promising insecticidal effect. The major constituents, himachalenes and atlantones, most likely accounted for the lethal action. Toxic activity increased with increasing concentrations. The highest concentration exhibited 100% mortality at 10,000 µg/ml. Similar positive effect of *Cedrus deodara* oil on mortality was obtained by Singh *et al.*, (1989) against *Callosobruchus chinensis*. Furthermore, *Cedrus deodara* oil is reported to show toxicity against *Lymnaea acuminate* when combined with extracts of *Azadirachta indica* and *Embelia ribes* (Rao and Singh 2001).

In the present investigation camphor oil also showed 100% mortality in contact bioassay at 2.25% while in fumigant bioassay, it caused 52% mortality at 450µl/l^{-1} of air. Earlier attempts to explore the toxicity of eucalyptus oil against different insect pests have been made by several scientists. Al-Jabr, (2006) showed 100% mortality of *Oryzaephilus surinamensis* obtained with *Cinnamomum camphora*. Liu *et al.*, (2006) showed insecticidal activity of *Cinnamomum camphora* against *Bruchus rugimensis* and *Sitophilus oryzae* at concentration of 1000µg/g. In another study, camphor applied at the dose of 60 µg/insect or more was significantly more toxic to the beetles compared with the controls, producing 100% mortality of all the four beetle species i.e. *Sitophilus granaries*, *Sitophilus zeamis*, *Tribolium castanaeum* and *Prostephanus truncates* within 48 hrs of application (Obeng-Ofori *et al.*, 2010).

In the present study eucalyptus oil showed the contact toxicity against *Corcyra cephalonica* larvae with the percent mortality 87.75% at 2.25% concentration. In fumigant toxicity it produced 57.14% larval mortality at the concentration of 450 μlL^{-1} air. In other study essential oils obtained from *Gomortega keule*, *Laurelia sempervirens*, *Origanum vulgare*, *Eucalyptus globulus*, and *Thymus vulgaris* were analyzed by gas chromatography and mass spectrometry and evaluated for their toxicity against adults of *Sitophilus zeamais* (Motschulky) and *Acanthoscelides obtectus* (Say) (Coleóptera). The essential oils of *Eucalyptus globulus* and *Thymus vulgaris* were most effective against *Sitophilus zeamais* (Magalisl *et al.*, 2008). Eucalyptus (*Eucalyptus globulus*) was also tested for insecticidal activity against *Callosobruchus maculatus* (L.) and *Sitophilus oryzae* (L.) adults. *Callosobruchus maculatus* was more sensitive than *Sitophilus oryzae* to the essential oils of *Eucalyptus globulus* and showed the LC_{95} value 3.66 µl/ 50ml air, while the LC_{95} value was 8.73 µl/ 50ml air for *Sitophilus oryzae* at the same exposure period (Ahmed and Salam, 2010). Negahban and Moharramipour, (2007) who found that the essential oils of *Eucalyptus intertexta*, *Eucalyptus sargentii* and *Eucalyptus camaldulensis* caused high mortality rate in *Callosobruchus maculatus* compared with *Sitophilus oryzae*. The insecticidal activity of *Eucalyptus globulus* (Mirtaceae) essential oil was tested against *Aphis gossypii* (Hemiptera, Aphididae) adults. The screening bioassay showed significantly high insecticidal activity (55-100%) at 3000, 6000, 12000 and 18000 ppm within first four hrs which increased upto 84-100% at 24 hrs (Mareggiani *et al.*, 2008).

In the present work the results revealed that at 24 hrs exposure, the 450 μlL^{-1} gave larval mortality (46%) and in contact application the 2.25% lemongrass oil gave (72.91%) mortality. Similar work of lemongrass oil done by several workers on insect pests. Bio-effect of five plant essential oils namely lemongrass (*Cymbopogon citratus*), apple mint (*Mentha rotandifolia*), dragonhead (*Dracocephalum moldavica*), pennyroyal (*Mentha pulegium*) and yarrow (*Achillea millefolium*), were tested as seed

protectants at concentrations of 1.0, 0.5 and 0.25% for the *Callosobruchus maculatus*. Apple mint, pennyroyal and lemongrass essential oils caused very high mortalities between larval and pupal stage (98.12, 97.73 and 92.32%) respectively (Aziz and Abbass, 2010). *Monodora myristica* was toxic with LD_{50} value of 0.346 for *Callosobruchus macultus*, while *Cymbopogon citrates* was toxic with LD_{50} 0.560 for *Sitophilus zeamis* (Owolabi *et al.*, 2009). Opareke and Dike, (1996) had attributed the effectiveness of *Cymbopogon citratus* against infestation of *Callosobruchus maculatus* to the high citral (neral and geranial) present in it. The evaluation of the effect of essential oils of *Pelargonium graveolens* and *Cymbopogon citratus* on maize weevil (*Sitophilus zeamis*) has assigned the most significant insecticidal activity against it with a maximum mortality rate of 100%. The essential oils *Pelargonium graveolens* and *Cymbopogon citratus* were found to have high contact and ingestion toxicity than fumigant/respiratory poison. This was evident from 90% mortality of weevils that come in contact or ingested contaminated food and only 40% when inhaled (Kabera *et al.*, 2011).

Present work on peppermint oil showed that larval mortality (74%) obtained at the highest concentration (2.25%) in contact application. In fumigation method mortality for *Corcyra cephalonica* larvae was 52.08% at the highest concentration 450 μlL^{-1} of air. Previous research testified that plant derived essential oils exhibited strong toxic effects on different pests. Insecticidal effect of volatile oils from peppermint (*Mentha piperita*), basil (*Ocimum basilicum*), lemon (*Citrus limon*) and orange (*Citrus sinensis*) against two museum insect pests was evaluated by fumigation test. Results of the study revealed that peppermint oil offered the highest toxicity to adults and larvae of the black carpet beetle and cigarette beetle at LD_{50} level. Among the four volatile oils, the orange oil was less toxic to adult and larvae of both species. There are numerous reports on the insecticidal activity of the volatile oils from peppermint species (Klingauf *et al.*, 1983 and Shaaya *et al.*, 1991). Mahmoudvand *et al.*, (2011) investigated toxicity of essential oils extracted from *Lippia citrodora* Kunth., *Rosmarinus officinalis* L., *Mentha*

piperita L. and *Juniperus* Sabina L. against adults of cowpea weevil, *Callosobruchus maculatus* (Col.: Bruchidae). Lowest concentration of essential oil of *Mentha piperita* (4.28 µl/L air) killed 5% of insects after 3 hrs exposure and 7.5%, 20% and 37.5% after 9, 12 and 24 hrs exposure, respectively. *Mentha piperita* essential oil was significantly more toxic to *Callosobruchus maculatus* than other essential oils which were reported in this study.

According to Tah *et al.*, (2011), essential oils of plants *Mentha piperita* and *Eucalyptus platyphylla* caused the death of adult *Aenasius advena*, *Cimex hemipterus* and *Tribolium castaneum* in 24 hrs of treatment. The effectiveness of *Mentha piperita* was observed only with high concentrations (16 and 33.3 µl/l). At these concentrations, the oil of *Eucalyptus platyphylla* induced mortality rate below 70%. The application of essential oils of two species of aromatic plants (*Eucalyptus platyphylla* and *Mentha piperita*) on adults of *Aenasius advena*, *Cimex hemipterus* and. *Tribolium castaneum* showed great sensitivity of the latter to these biopesticides, with mortality rates ranging from 78.3 to 98.61% at the highest concentration of *Mentha piperita*.

Apart from testing the essential oils alone, different combinations were also tested against the larvae of *Corcyra cephalonica*. In combination treatment, all different combinations showed synergistic effect. In contact bioassay at 1.75% concentration, cedarwood and eucalyptus when applied individually produced 74% and 68% larval mortality respectively while in the combination treatment at the same concentration they exhibited 100% larval mortality. In fumigation application at 450 μlL^{-1} of air cedarwood and eucalyptus oil resulted in 54% and 58% larval mortality while in contrast there combination exhibited 78% larval mortality. Chaubey, 2011 studied the combinatorial action of essential oils towards a serious insect pest of pulses, *Callosobruchus chinensis*. Sublethal concentrations of *Trachyspermum ammi Anethum graveolens*; *Anethum graveolens* and *Nigella sativa* and *Nigella sativa* and *Trachyspermum ammi* essential oil

combinations significantly reduced the oviposition potential of the *Callosobruchus chinensis* in comparison to the control group and it was found that combinations of *Trachyspermum ammi*, *Anathum graveolens* and *Nigella sativa* essential oils had insecticidal properties against adults of *Callosobruchus chinensis* in synergistic manner. Ngamo *et al.*, (2007) have reported similar results against *Sitophilus oryzae* when applied essential oils alone or in balanced combinations. The rapid action of essential oils against insects is indicative of their neurotoxic mode of action interfering with neuromodulator octopamine (Kostyukovsky *et al.*, 2002) or with GABA-gated chloride channels (Priestley *et al.*, 2003). Combinations of essential oils probably target both pathway of toxicity in insects and essential oils could be the source of active components showing synergism.

The present study demonstrated that the cedarwood oil along, and combinations of cedarwood with eucalyptus, peppermint and camphor oil when applied on the larvae of *Corcyra cephalonica* at different concentrations, had deleterious effects on the female reproductive system. There was overall reduction in size of ovarioles due to shrinkage in ovariole length, reduction in number of developing oocytes etc. Similar observations were obtained by several workers. In ovipositional behavioural experiment cedarwood oil treated chickpea, *Cicer aeritinum* grains had 134.3, 114.0 and 112.3 mean number of eggs/5 females of *Callosobruchus chinensis* while neem oil had 98.3, 118.7 and 57 at 3, 2 and 1% concentrations respectively (Raguraman and Singh, 1997). With regards to oviposition of *Callosobruchus chinensis*, *Origanum majorana* at 5 ppm reduced the number of egg laid (Sharma *et al.*, 2011). The insecticidal activity of essential oils extracted by hydro distillation from three aromatic plants from *Ageratum conyzoides*, *Citrus aurantifolia* and *Melaleuca quinquenervia* was tested on the cowpea weevil, *Callosobruchus maculatus*. The number of laid eggs was inversely proportional to the essential oils concentrations tested (Louis *et al.*, 2010). In adult females of *Cohnella phaseoli* treated with vapours from doses of 5 ml or more *Acorus calamus* oil, the fecundity was reduced, the percent reduction depending on the exposure period.

Indian oil was less effective than Yugoslavian or Russian oil in this respect (Rahman and Schmidt, 1998). The effect of Indian *Acorus calamus* oil vapours on fecundity was reported by Saxena *et al.*, (1976) for *Tribolium castaneum*, *Sitophilus oryzae*, *Callosobruchus chinensis*, *Trogoderma granarium* Everts and *Anthrenus flavipes*. In a separate study essential oils from *Mentha viridis*, *Eucalyptus globulus*, *Mentha microphylla*, *Rosinus officinalis* and *Lavandula hybrida* reduced the number of eggs laid, where the fecundity was adversely influenced at two levels. The first is the inhibition of oogenesis and the second the increased egg retention in the lateral oviducts (Papachristos and Stampoulos, 2002). Effect of methanolic extracts of *Eupatorium odoratum* (Compositae) leaves on the ovary of the coconut pest, *Oryctes rhinoceros* L. (Coleoptera: Scarabaeidae) was studied. Number of follicles and weight of ovary were reduced significantly ($p < 0.05$). Length of germarium was reduced in10µl treatment while it was increased in the 20 µl. Vitellarium and ovariole length was increased and reduced in 10 µl and 20 µl treated insects respectively (Sreelatha and Geetha, 2010). Ovariole size, length, and oocyte number were reduced in *Dysdercus cingulatus* treated with extracts of *Vitex negundo* and *Eupatorium odoratum* (Prameela, 1997) and in *Corcyra cephalonica* emerged from neem fed larvae (Chanda and Chakravorty, 2000). Reduced size of ovary was reported in *Bactrocera cucurbitae* reared on food treated with methanolic extract of *Acorus calamus*. The extract of *A. calamus* when fed with the food substances adversely affected the size of reproductive organs. The vapours of *Acorus calamus* possess a specific effect on egg resorption in females. This is due to abnormal functioning of follicular cells, making the gravid insects infecund (Nair and Thomas, 2001).

From these findings we can conclude that all the five essential oils tested are toxic to *Corcyra cephalonica*. A good level of control of the test insect (especially anti-reproductive effect) in this study was achieved with applying the essential oils cedarwood alone and with different combinations. The mode of action of these essential oils is yet to be confirmed but it appear that death of the larva, oviposition inhibition may be

due to the inhibition of different processes of the insect metabolism. In combination treatment essential oils could be the source of active components showing synergism. Furthermore, exploration of mode of actions of essential oil constituents in combination will definitely help in understanding the mechanism of action in synergism.

Application of essential oils to grain seeds for storage is an inexpensive and effective technique, and its easy adaptability will give additional advantages leading to acceptances of this technology by farmers. A study to improve the effectiveness of botanical derivatives as insecticides will benefit agricultural sectors of developing countries, as these substance are not only of low cost, but also have less environmental impact in term of insecticidal hazard. However its problem of volatility can be resolved through a controlled release formulation of the active components of essential oils that allow smaller quantities of insecticide to be used more effectively over a given time interval.

Pictures

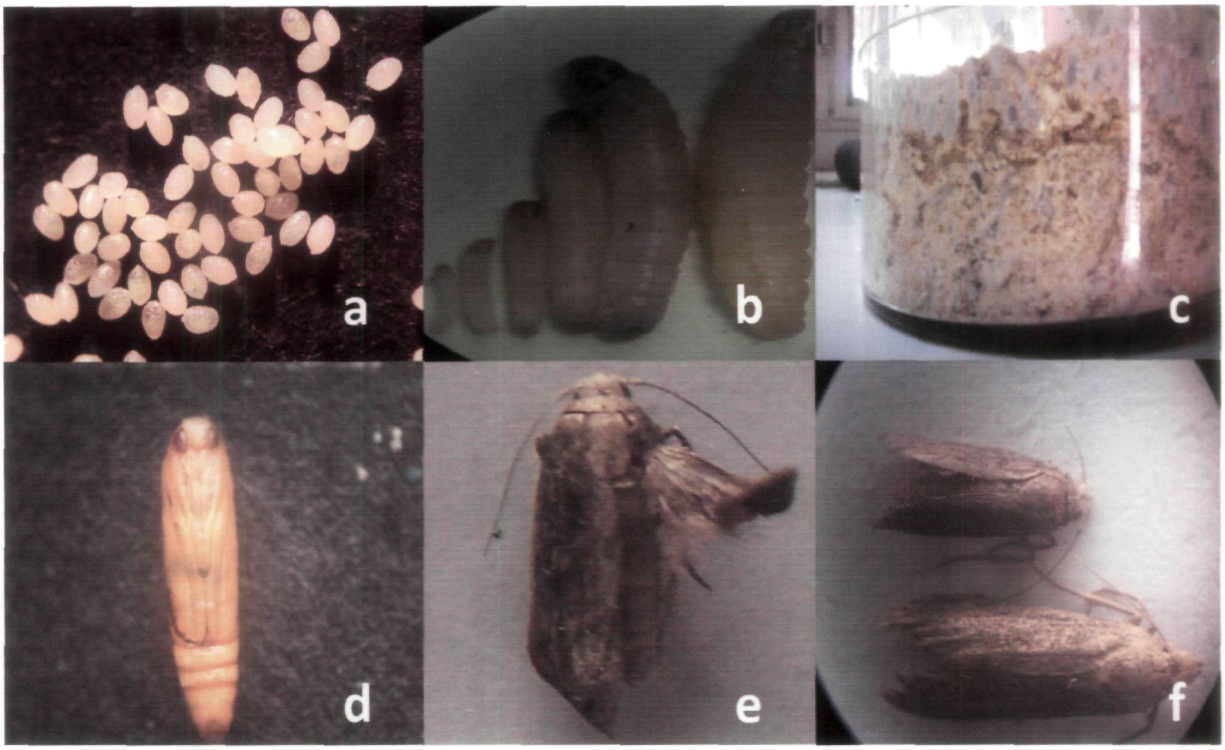
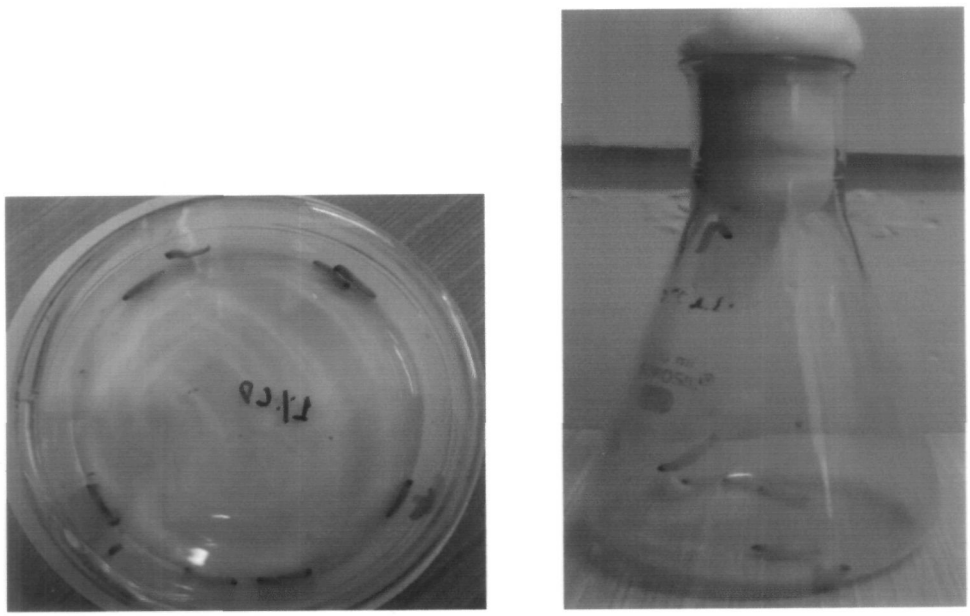


Figure 1. Normal biology of the *C. cephalonica* (a). Eggs (b). Instars (c). Cocoons (d). Pupa (e). Newly emerged adult (f). Male (top), female (bottom).



(A) (B)

Fig 2. (A) Contact Bioassay and (B) Fumigant Bioassay

Fig 3. Dead larvae due to the toxic effect of essential oils.

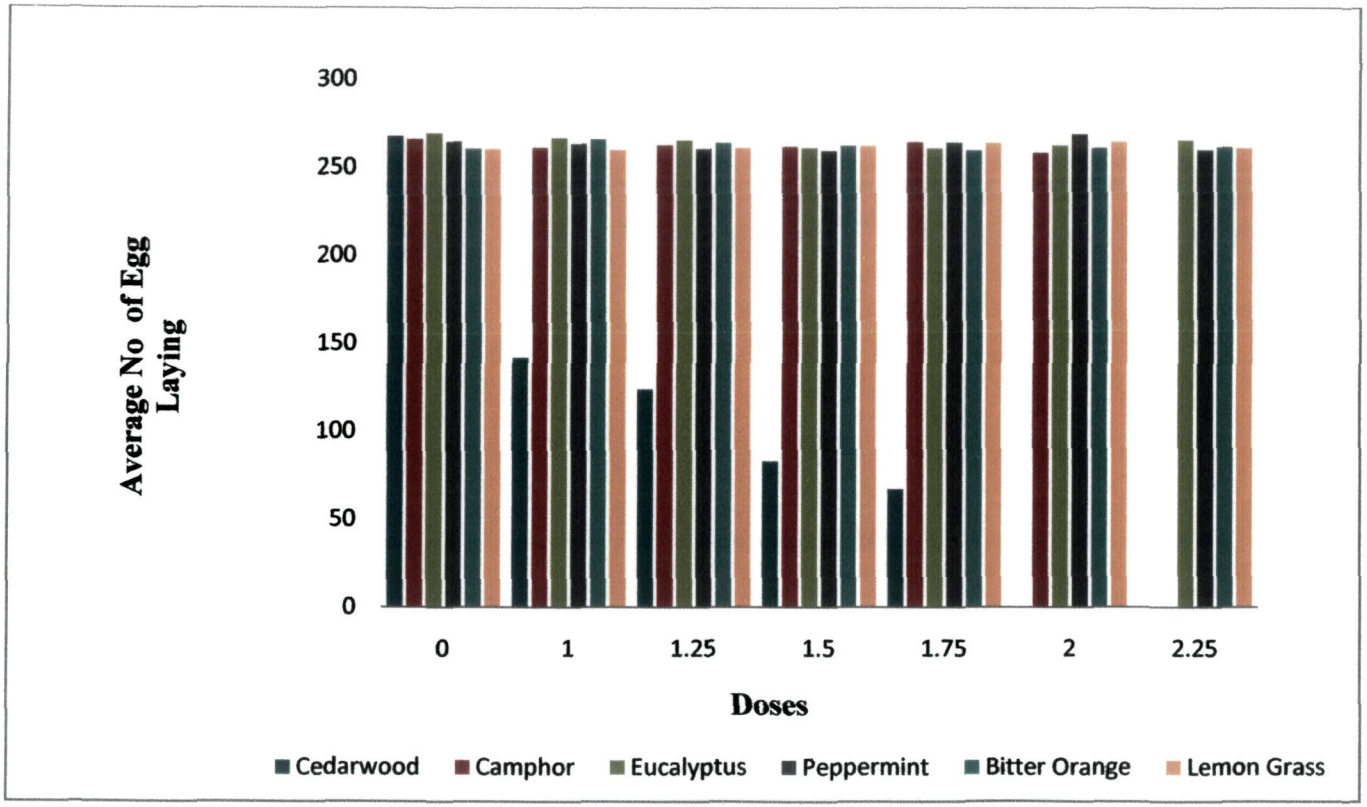


Fig 4. Average number of eggs laid by *C. cephalonica* via contact application of different oils at varying concentrations.

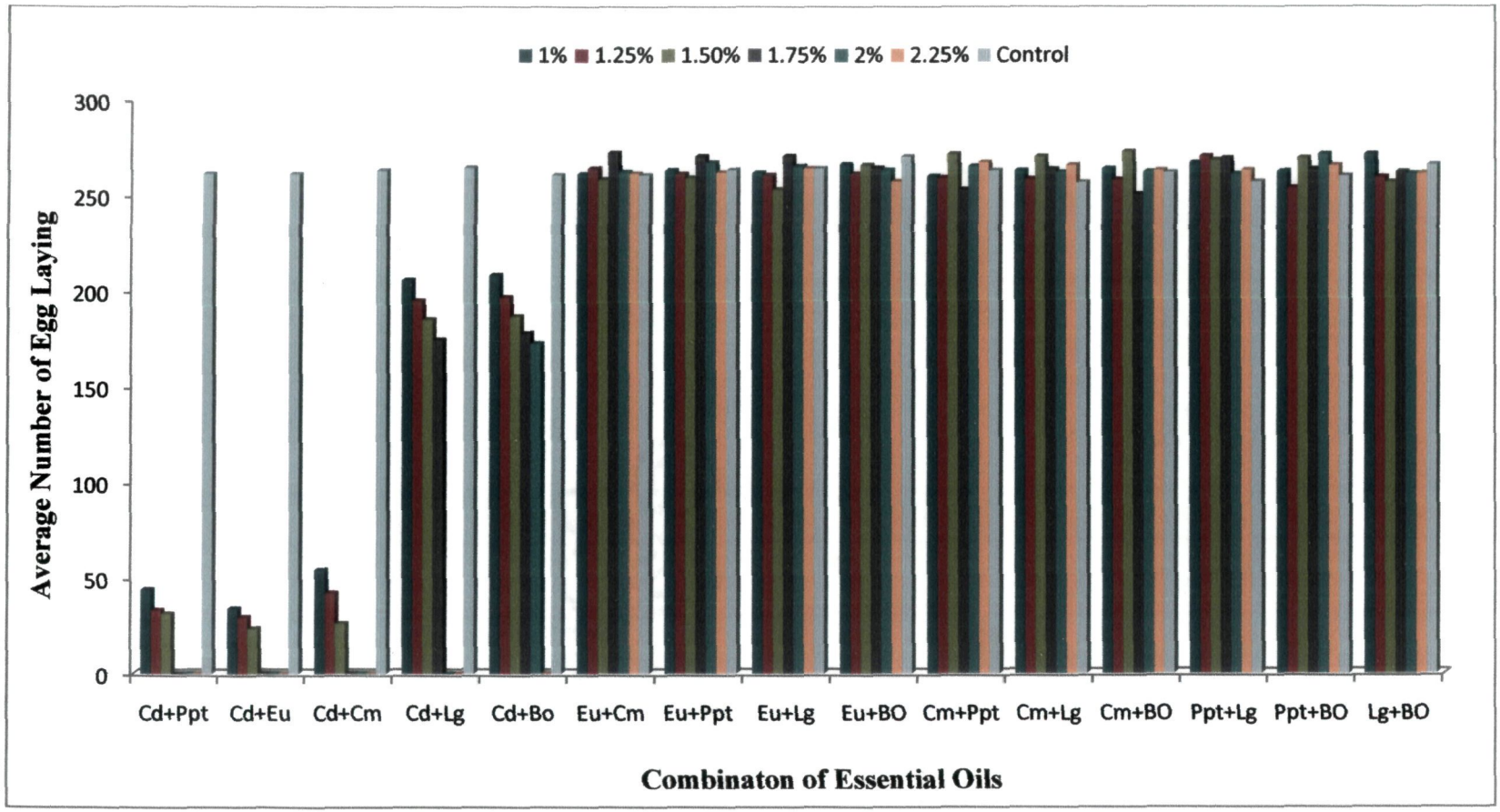


Fig 5. Average number of eggs laid by *C. cephalonica* via contact application of combination of different oils at varying concentrations.

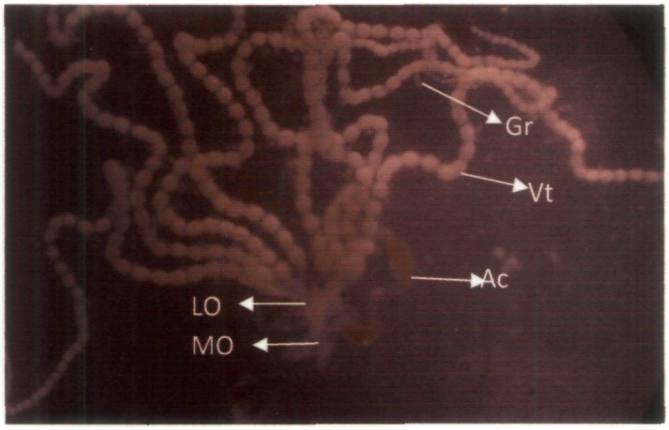


Fig 6. Ovarioles of the female emerged from untreated 4th instar larvae of *Corcyra cephalonica* (at12.5x X 1x). Gr (Germarium), Vt (Vitellarium), LO (Lateral Oviduct), MO (Medain Oviduct), Ac (Accessory gland).

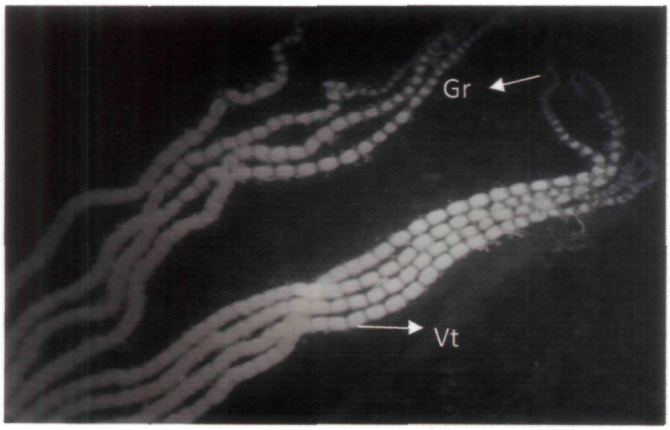


Fig 7. Ovarioles of the female emerged from control 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 1x). Gr (Germarium), Vt (Vitellarium).

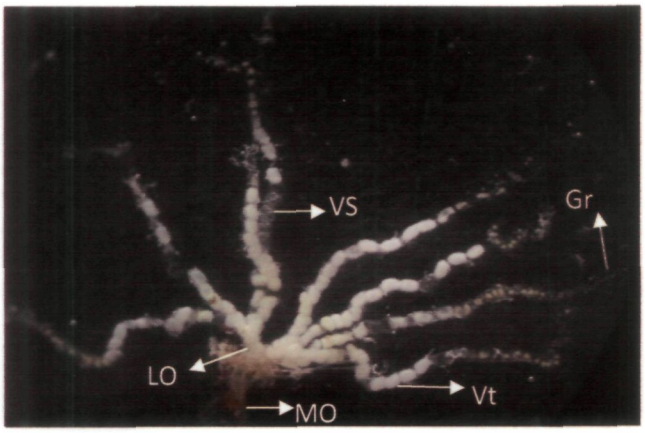


Fig 8. Ovarioles of the female emerged from 1% cedarwood oil treated 4th instar larvae of *Corcyra cephalonica* (at12.5x X 1x). Gr (Germarium), Vt (Vitellarium), VS (Vacant Space), LO (Lateral oviduct), MO (Medain Oviduct).

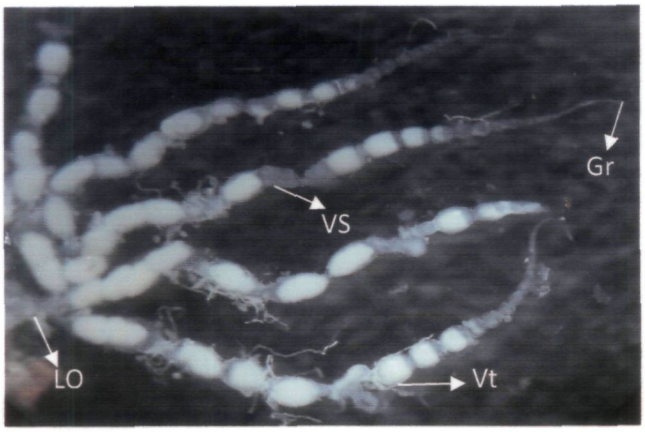


Fig 9. Ovarioles of the female emerged from 1.25% cedarwood oil treated 4th instar larvae of *Corcyra cephalonica* (at12.5x X 2x). Gr (Germarium), Vt (Vitellarium), VS (Vacant space), LO (Lateral oviduct).

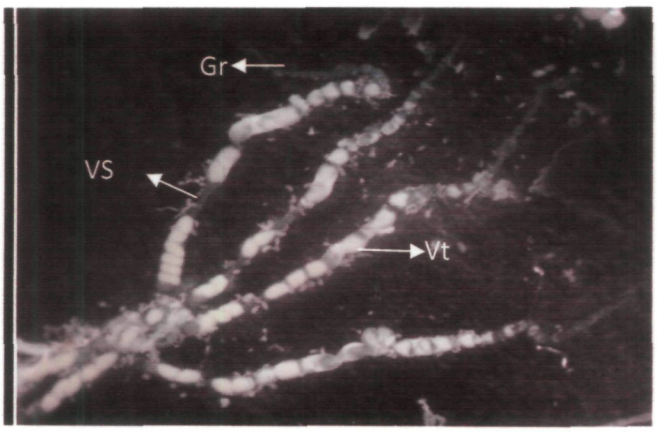


Fig 10. Ovarioles of the female emerged from 1.5% cedarwood oil treated 4th instar larvae of *Corcyra cephalonica* (at12.5x X 1x). Gr (Germarium), Vt (Vittelarium), VS (Vacant space).

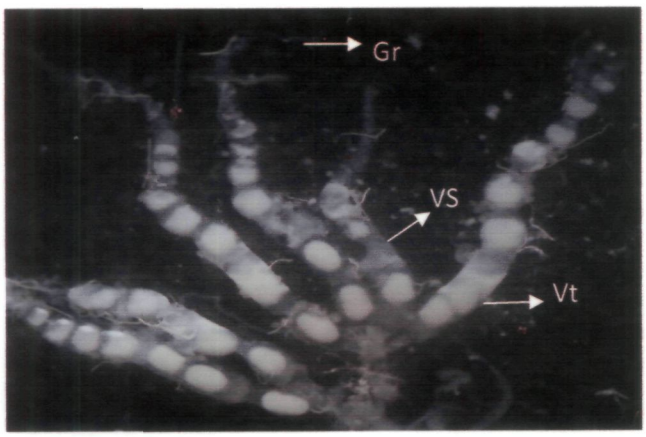


Fig 11. Ovarioles of the female emerged from 1.75% cedarwood oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 5x). Gr (Germarium), Vt (Vitellarium), VS (Vacant space).

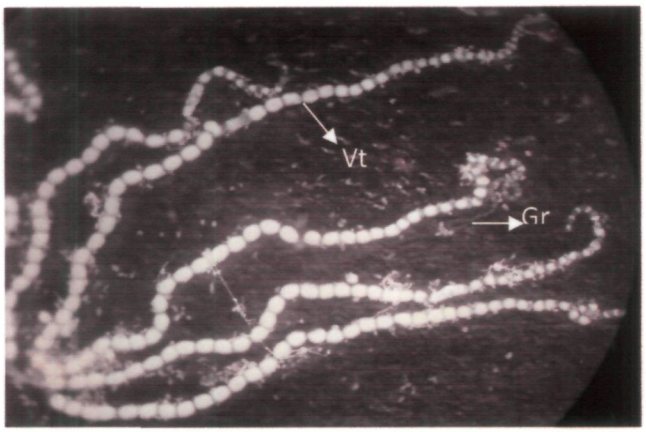


Fig12. Ovarioles of the female emerged from 2.25% camphor oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 1x). Gr (Germarium), Vt (Vitellarium).

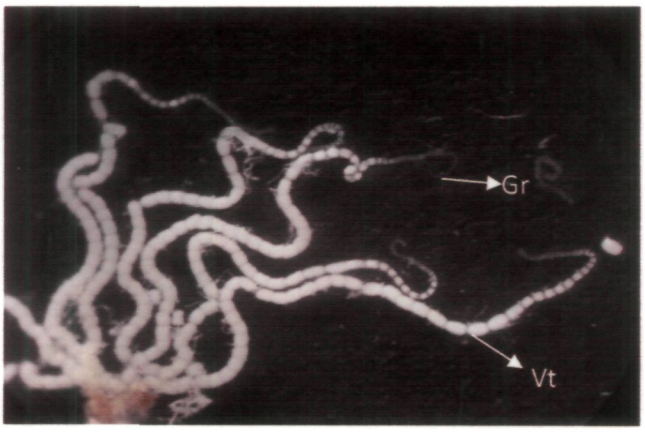


Fig 13. Ovarioles of the female emerged from 2.25% eucalyptus oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 1x). Gr (Germarium), Vt (Vitellarium).

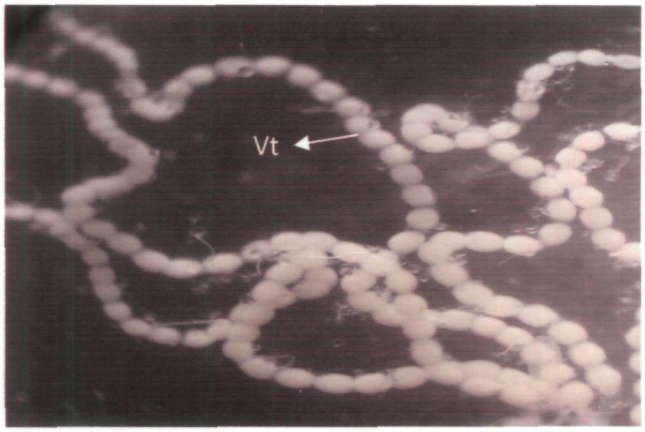


Fig 14. Ovarioles of the female emerged from 2.25% lemongrass oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium).

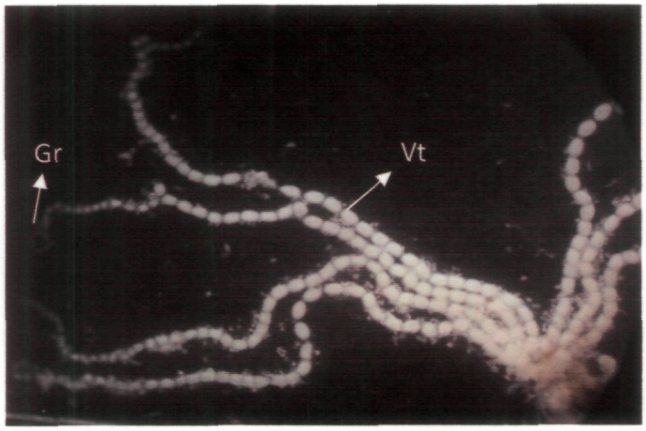


Fig 15. Ovarioles of the female emerged from 2.25% peppermint oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 1x). Gr (Germarium), Vt (Vitellarium).

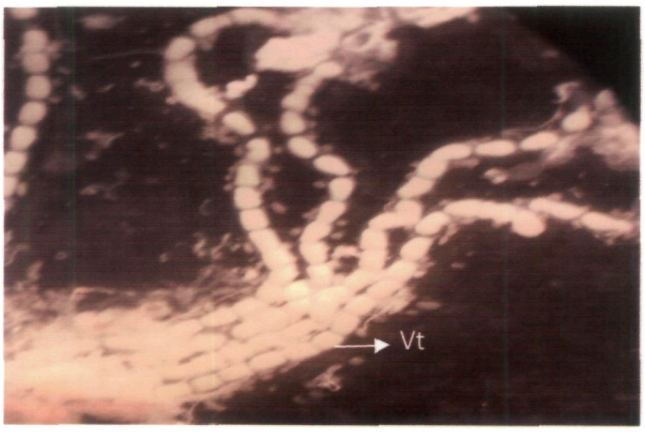


Fig 16. Ovarioles of the female emerged from 2.25% bitter orange oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium).

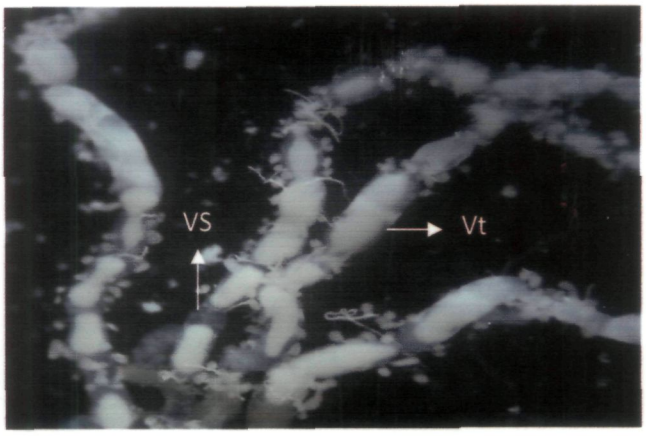


Fig 17. Ovarioles of the female emerged from 1% cedarwood+eucalyptus oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 3x). Vt (Vitellarium), VS (Vacant space).

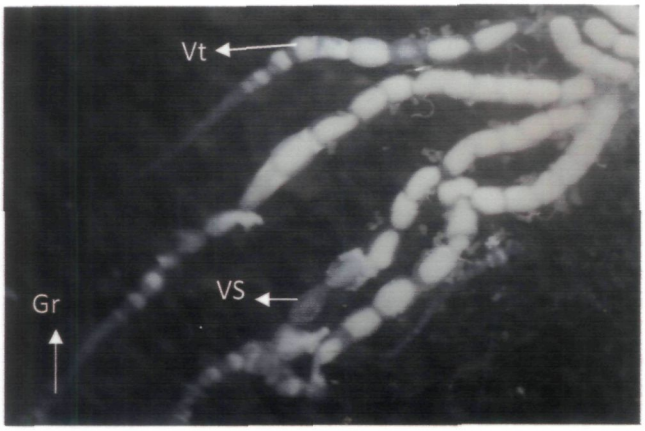


Fig 18. Ovarioles of the female emerged from 1.25% cedarwood+eucalyptus oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium), VS (Vacant space).

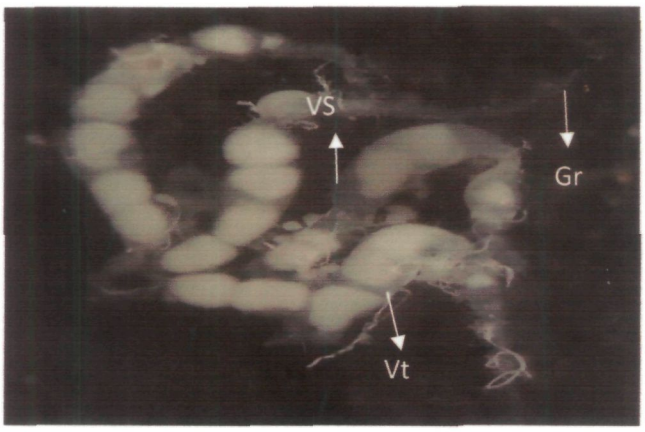


Fig 19. Ovarioles of the female emerged from 1.5% cedarwood+eucalyptus oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 5x). Gr (Germarium), Vt (Vitellarium), VS (Vacant space).

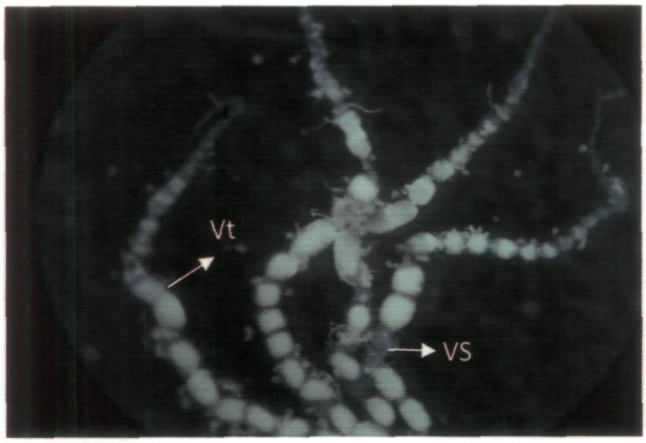


Fig 20. Ovarioles of the female emerged from 1% cedarwood+ peppermint oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium).

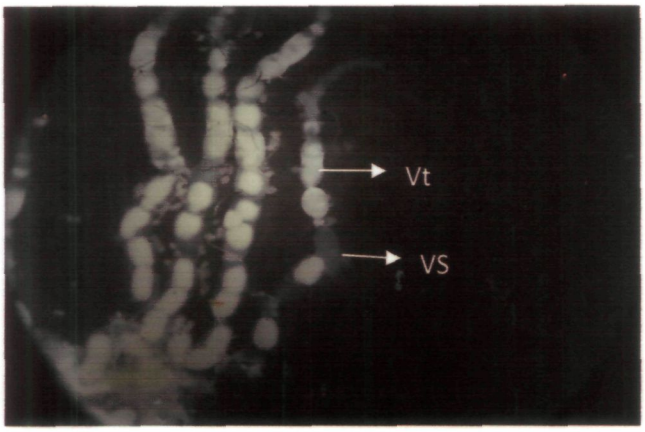


Fig 21. Ovarioles of the female emerged from 1.25% cedarwood+peppermint oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium), VS (Vacant space).

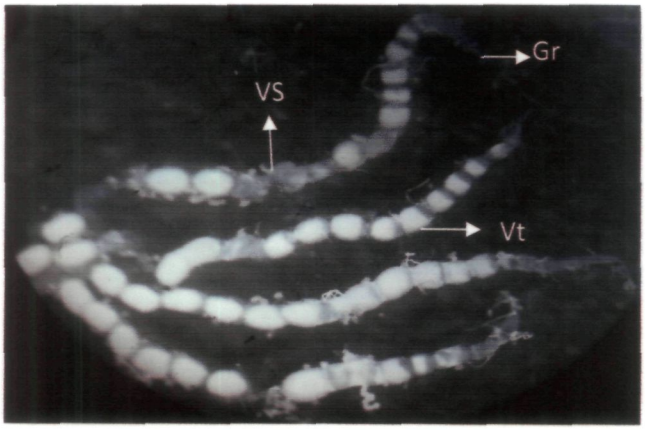


Fig 22. Ovarioles of the female emerged from 1.5% cedarwood+peppermint oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium), VS (Vacant space).

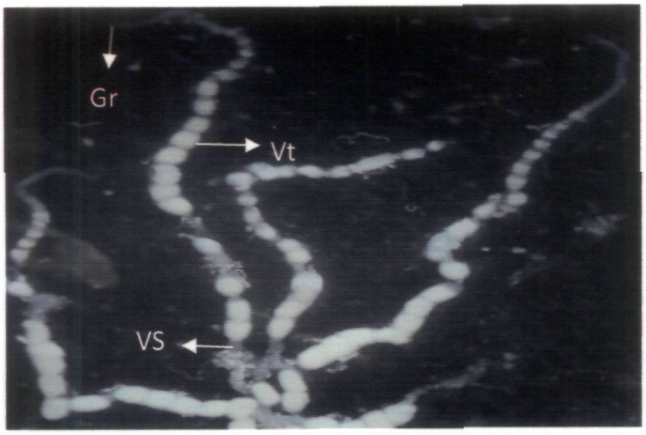


Fig 23. Ovarioles of the female emerged from 1% cedarwood+camphor oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium), VS (Vacant space).

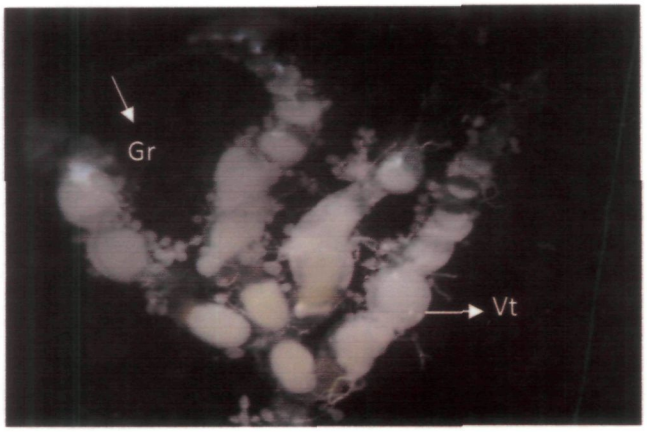


Fig 24. Ovarioles of the female emerged from 1.25% cedarwood+camphor oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 3x). Gr (Germarium), Vt (Vitellarium).

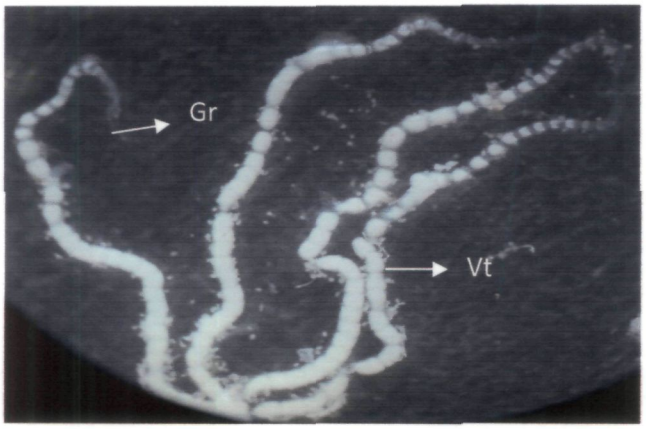


Fig 25. Ovarioles of the female emerged from cedarwood+bitter orange oil oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 1x). Gr (Germarium), Vt (Vitellarium).

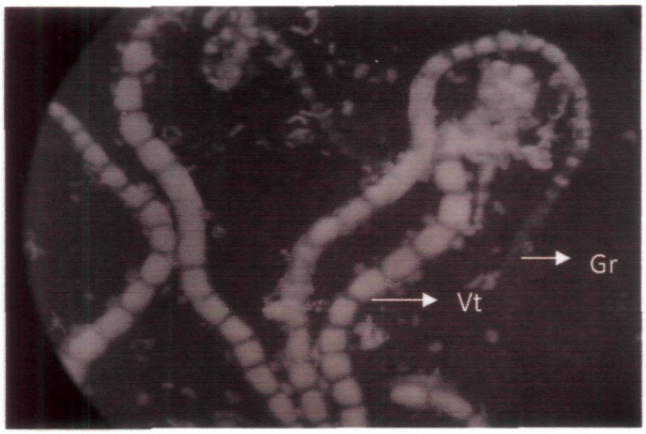


Fig 26. Ovarioles of the female emerged from cedarwood+lemongrass treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 1x). Gr (Germarium), Vt (Vitellarium).

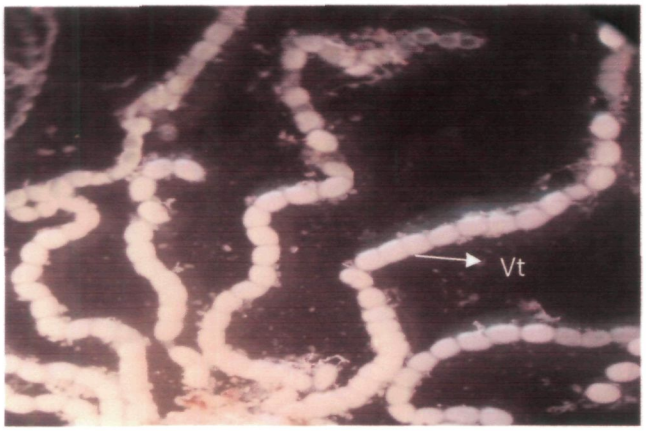


Fig 27. Ovarioles of the female emerged from eucalyptus+camphor treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium).

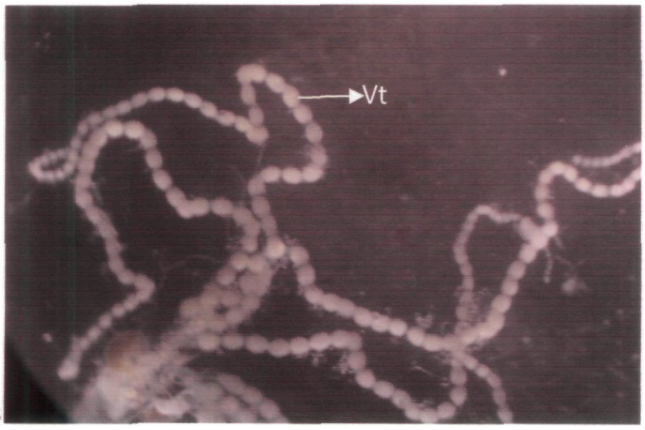


Fig28. Ovarioles of the female emerged from camphor+bitter orange oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium).

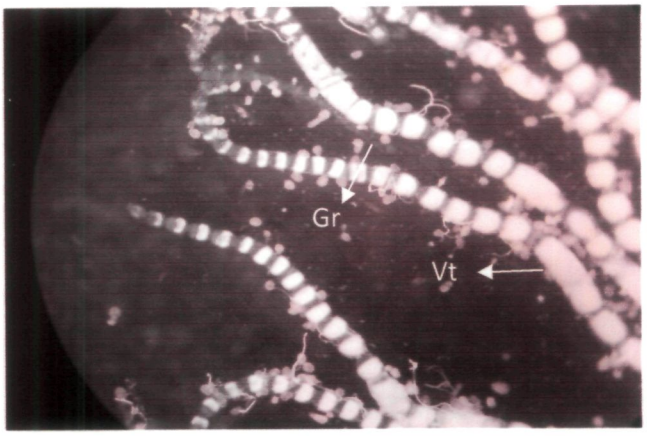


Fig29. Ovarioles of the female emerged from camphor+lemongrass oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium).

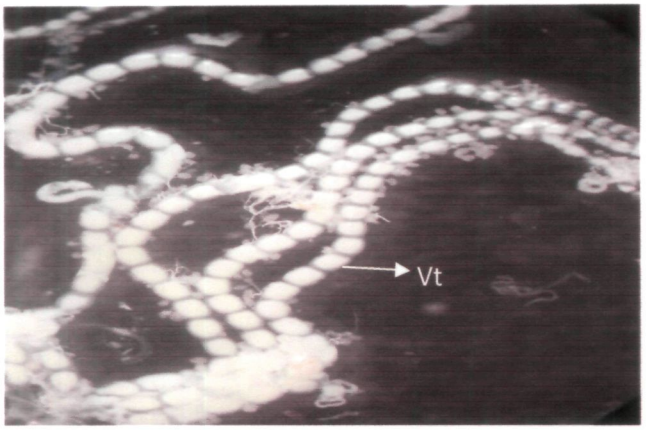


Fig 30. Ovarioles of the female emerged from camphor+peppermint oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium).

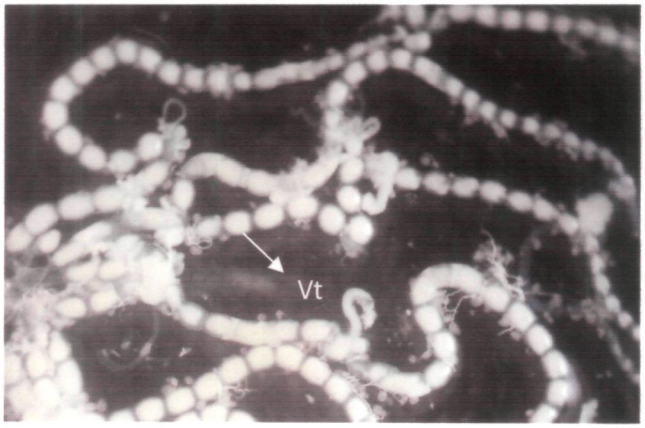


Fig31. Ovarioles of the female emerged from eucalyptus+bitter orange oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Vt (Vitellarium).

Fig 32. Ovarioles of the female emerged from eucalyptus+lemongrass oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium).

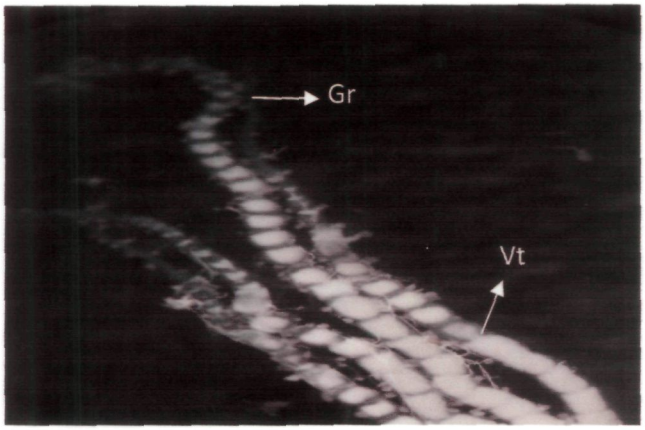


Fig 33. Ovarioles of the female emerged from eucalyptus+peppermint oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium).

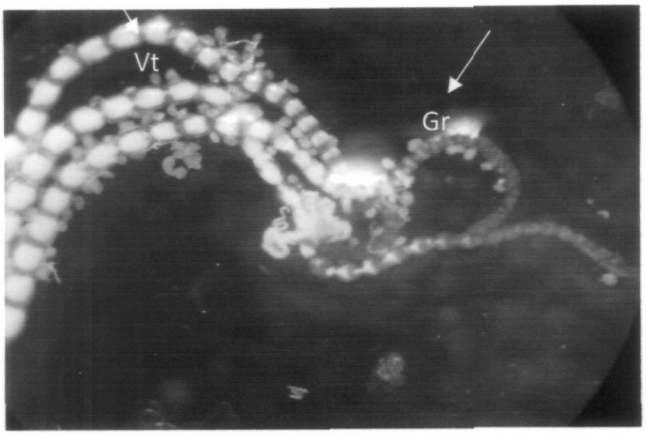


Fig 34. Ovarioles of the female emerged from peppermint+lemongrass oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium).

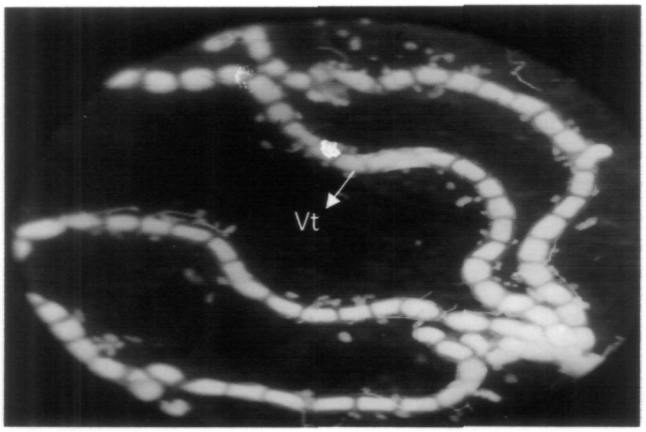


Fig35. Ovarioles of the female emerged from peppermint+bitter orange oil treated 4th instar larvae of *Corcyra cephalonica* (at 12.5x X 2x). Gr (Germarium), Vt (Vitellarium).Vt (Vitellarium).

References

REFERENCES

Aboua, L.R.N., Seri-Kouassi, B.P., and Kova, H.K., 2010. Insecticidal activity of essential oils from three aromatic plants on *Callosobruchus maculates* F. in Cote D ivoire. *European Journal of Scientific Research* 39, 243-250.

Achremowicz, J., 1995. Badania nowych aficydow pochodzenia roslinnego, *Pestycydy* 4, 27-36.

Ahmed, M.E., and Abd El-Salam 2010. Fumigant toxicity of seven essential oils against the cowpea weevil, *Callosobruchus maculates* (F.) and the rice weevil, *Sitophilus oryzae* (L.). *Egyptian Academic Journal of Biological Sciences* 2, 1-6.

Al-Jabr, AM., 2006. Toxicity and repellency of seven plant essential oils to *Oryzaephilus surinamensis* (Coleoptera: Silvanidae) and *Tribolium castaneum* (Coleoptera: Tenebrioidae). *Scientific Journal of King Faisal University* 7, 49-60.

Ansari, M.A., and Razadan, R.K., 1994. Repellent action of *Cymbopogon martini martini* Staf. Var. Sofia against mosquitoes. *Indian Journal of malariology* 31, 95-102.

Arabi, F., Moharramipour, S., and Sefidkon, F., 2008. Chemical composition and insecticidal activity of essential oil from *Perovskia abrotaoides* (Lamiaceae) against *Sitophilus oryzae* (Coleoptera: Curculionidae) and *Tribolium castanaeum* (Coleoptera: Tenebrionidae). *International Journal of Tropical Insect Science* 28, 144-150.

Aziz, E.E., and Abbass, M.H., 2010. Chemical composition and efficiency of five essential oils against the pulse beetle *Callosobruchus maculates* (F.) on *Vigna radiate* seeds. *Journal of Agriculture and Environmental Science* 8, 411-419.

Bakr, R.F.A., Hoda, Abdel-Fattah, H.M., Salim, N.M., and Atiya, H.N., 2010. Insecticidal activity of four volatile oils on two museum insect pests. *Egyptian Academic Journal of Biological Sciences* 2, 57- 66.

Batish, D., Singh, H., Kohli, R and Kaur, S., 2008. Eucalyptus essential oil as a natural pesticide. *Forest Entomology and Management* 256, 2166-2174

Boelens, M.H., and Jimenez, R., 1989. The chemical composition of the peel oils from unripe and ripe fruits of bitter orange, citrus. *Flavour and Fragrance Journal* 4, 139-142.

Brooker, M.I.H. and Kleinig D.A., 2006. Field guide to eucalyptus .vol 1. South Eastern Australia (third edition) Bloomings, Melbourne.

Caroll, S., and Loye, J., 2006. Field test of lemon eucalyptus repellent against Leptoconops midges. *Journal of the American Mosquito Control Association* 22, 483-488.

Chanda, S. and Chakravorty, S., 2000. Effect of neem mixed larva food on development of reproductive organs and nature of fertility of the emerged morphs of *Corcyra cephalonica* (Stainton) (Lepidoptera : Pyralidae). *Annals of Entomology* 18, 19-26.

Chaubey, K.M., 2011. Combinatorial action of essential oils towards pulse beetle *Callosobruchus chinensis* Fabricius (Coleoptera: Bruchidae). *International Journal of Agricultural Research* 6, 511-516.

Chaubey, M.K., 2008. Fumigant toxicity of essential oils from some common spices against pulse beetle, *Callosobruchus chinensis* (Coleoptera: Bruchidae). *Journal of Oleo Science* 57, 171-179.

Chaudhary, A., Sharma, P., Nadda, G., Tewary, D.K., and Singh, B., 2011. Chemical composition and larvicidal activities of the Himalayan cedar, *Cedrus deodara* essential oil and its fractions against the diamondback moth, *Plutella xylostella*. *Journal of Insect Science* 11, 1-10.

Chen, H., Akinkurolere, R.O., and Zhang, H., 2011. Fumigant activity of plant essential oil from *Armoracia rusticana* (L.) and *Sitophilus zeamis* (Coleoptera: Curculionidae). *African Journal of Biotechnology* 10, 1200-1205.

Chouchi, D., Barth, D., Reverchon, E., and della Porta, E., 1996. Bigarade peel oil fractionation by supercritical carbon dioxide desorption. *Journal of Agricultural and Food Chemistry* 44, 1100-1104.

Clemente, S.V., Mareggiani, G., Broussalis, A., and Ferrare, G., 2006. Actividad Insecticida de 1,8-cinelo sobre mosca de los frutos, *Ceratitis capitata* Wied. (Diptera: Tephritidae). *Dominguezia* 23, 29-34.

Cosimi, S., Rossi, E., Cioni, P.L., and Canale, A., 2009. Bioactivity and qualitative analysis of some essential oils from Mediterranean plants against stored-product pests: evaluation of repellency against *Sitophilus zeamais* Motschulsky, *Cryptolestes ferrugineus* (Stephens) and *Tenebrio molitor* (L.). *Journal of Stored Products Research* 45, 125-132.

Desmarchelier, J.M., 1994. Carbonyl sulphide as fumigant for control of insects and mites. Proceedings of the sixth international working conference on stored product protection. 75-81.

Dezfouli, E., Moharramipour, S., and Goldasteh, S.H., 2010. Ovicidal, larvicidal and oviposition deterrency effects of essential oil from *Thymus vulgaris* L. (Lamiaceae) on *Callosobruchus maculates* (F.) (Col., Bruchidae). *Journal of Entomological Research* 2, 73-84.

Dolan, M.C., Dietrich, G., Panella, N.A., Montenieri, J.A., and Karchesy, J.S., 2007. Biocidal activity of three wood essential oils against *Ixodes scapularis* (Acari: Ixodidae), *Xenopsylla cheopis* (Siphonaptera: Pulicidae), and *Aedes aegypti* (Diptera: Culicidae). *Journal of Economic Entomology* 100, 622-625.

Gbolade, A.A., Oyedele, A.O., Sosan, M.B., Adewoyin, F.B., and Soyelu, O.L., 2000. Mosquito repellent activities of essential oils from two Nigerian Ocimum species. *Journal of Tropical Medicinal Plants* 1, 146-148.

Gillij, Y.G., Gleiser, R.M., and Zygadlo, J.A., 2008. Mosquito repellent activity of essential oils of aromatic plants growing in Argentina. *Bioresource Technolology* 99, 2507-2515.

Govere J, Durrheim, D.N., Du, T.N., Hunt, R.H., and Coetzee, M., 2000. Local plants as repellents against *Anopheles arabiensis*, in Mpumalanga Province, South Africa. *Central African Journal of Medicine* 46, 213-216.

Gupta, A., Sharma, S., and Naik 2011. Biopesticidal value of selected essential oils against pathogenic fungus, termites and nematodes. *International Biodeterioration and Biodegradation* 65, 703-707.

Hadis, M., Lulu, M., Mekonnen, Y., and Asfaw, T., 2003. Field trials on the repellent activity of four plant products against mainly Mansonia population in Western Ethopia. *Phytotherapy Research* 17, 202-205.

Harwood, S.H., Modenke, A.F., and Berry, R.E., 1990. Toxicity of peppermint monoterpenes to the variegated cutworm (Lepidoptera: Noctuidae). *Journal Economic Entomology* 83, 1761–1767.

Hori, M., 2003. Repellency of essential oils against the cigratte beetle *Lasioderma serricorne* (Fabricius) (Coleoptera: Anobiidae). *Applied Entomology and Zoology* 38, 467-473.

Huang, Y., Lam S.L., and Ho, S.H., 2000. Bioactivity of essential oil from *Elletaria ardamomum* (L.) Maton. to *Sitophilus zeamais* Motschulsky and *Tribolium castaneum* (Herbst). *Journal of Stored Products Research* 36, 107-117.

Hummelbrunner, A.L., and Isman, M.B., 2001. Acute, sublethal, antifeedant and synergistic effects of monoterpenoid essential oil compounds on the tobacco cut worm (Lepidoptera: Noctuidae). *Journal of Agricultural and Food Chemistry* 49, 715–720.

Isık, M., and Gorur, G., 2009. Aphidicidial activity of seven essential oils against the cabbage aphid, *Brevicoryne brassicae* L. (Hemiptera: Aphididae). *Munis Entomology and Zoology* 4, 424-431.

Isman, M.B., 2000. Plant essential oils for pest and disease management. *Crop Protection* 19, 603–608.

Jaenson, T.G., Palson K., and Borg – Karlson, A.K., 2006. Evaluation of extracts and oils of mosquito (Diptera : Culicidae) repellent plants from Sweden and Guinea – Bissan. *Journal of Medical Entomology* 43, 113-119.

Jalali, S.K., Venkatesan, T., Murthy, K.S., Rajaratnam, J., and Lalitha Y., 2007. Vacuum packaging of *Corcyra cephalonica* (Stainton) eggs to enhance shelf life for parasitization by the egg parasitoid *Trichogramma chilonis*. *Biological Control*, 41, 64-67.

Kabera, J., Gasogo, A., Uwamariya, A., Ugirinshuti, V and Nyetera, P., 2011. Insecticidal effects of essential oils of *Pelargonium graveolens* and *Cymbopogon citrates* on *Sitophilus zeamis* (Motsch.). *African Journal of Food Science* 5, 366-375.

Keita, S.M., Vincent, C., Schmit, J., Arnason, J.T., and Belanger A., 2001.Efficacy of essential oil of *Ocimum basilicum* L. and *O. gratissimum* L. applied as an insecticidal fumigant and powder to

control *Callosobruchus maculates* (Fab.). *Journal of Stored Products Research* 37, 339-349.

Klingauf, F., Bestman, H.J., Vostrowsky, O., and Michaelis, K., 1983. The effect of essential oils on insect pests. Mitteilugen der deutschen gesell schaft fur allgemeine and angewandte. *Entomologie* 4, 123-126.

Kostyukovsky, M., Rafaeli, A., Gileadi, C., Demehenko, N., and Shaaya, E., 2002. Activation of octopaminergic receptors by essential oil constituents isolated from aromatic plants: Possible mode of action against insect pests. *Pest Management Science* 58, 1101-1106.

Koul, O., **Walia, S., and Dhaliwal, G.S.,** 2008. Essential oils as green pesticides: Potential and Constraints. *Biopesticides International* 4, 63-84.

Krishna-Ayyar, P.N., 1930. A very destructive pest of stored products in South India *Corcyra cephalonica* (Stainton). *Bulletin of Entomological Research* 25, 155-169.

Kumar, R., Kumar, A., Prasal, C.S., Dubey, N.K., and Samant, R., 2008. Insecticidal activity *Aegle marmelos* (L.) Correa essential oil against four stored grain insect pests. *Internet Journal of Food Safety* 10, 39-49

Landolt, P.J., Hofstetter, R.W., and Biddick, L.L., 1999. Plant essential oils as arrestants and repellents for neonate larvae of the codling

moth (Lepidoptera: Totricidae). *Environmental Entomology* 28, 954-960.

Lee, B.H., Choi, W.S., Lee, S.E., and Park, B.S., 2001. Fumigant toxicity of essential oils and their constituent compounds towards the rice weevil, *Sitophilus oryzae* (L.). *Crop Protection* 20, 317 - 320.

Lee, B.H., Annis, P.C., Tumaalii, F., and Choi, W.S., 2004. Fumigant toxicity of essential oils from the Myrtaceae family and 1,8-cineol against 3 major stored-grain insects. *Journal of Stored Products Research* 40, 553-564.

Lee, S., Tsao, R., Peterson, C., and Coats, J.R., 1997. Insecticidal activity of monoterpenoids to Western corn root worm (Coleoptera: Chrysomelidae), twospotted spidermite (Acari: Tetranychidae) and Housefly (Diptera: Muscidae). *Journal of Economic Entomology* 90, 883–892.

Liu, C.H., Mishra, A.K., Tan, R.X., Tang, C., Yang H., and Shen, Y.F., 2006. Repellent and insecticidal activities of essential oils from *Artemisia princeps* and *Cinnamomum camphora* and their effect on seed germination of wheat and broad bean. *Bioresource Technology* 97, 1969-1973.

Liu, Z.L., Chu, S.S., and Jiang, G.H., 2011. Insecticidal activity and composition of essential oil of *Ostericum sieboldii* (Apiaceae) against *Sitophilus zeamis* and *Tribolium castanaeum*. *Records of natural products* 5, 74.

Louis, R.N.A., Philomene, P.S.K., and Herve, K.K., 2010. Insecticidal activity from three aromatic plants on *Callosobruchus maculatus* F. in Cote D' ivore. *European Journal of Scientific Research* 39, 243-250.

Lu, J., Wu, C., and Shi, Y., 2011. Toxicity of essential oil from *Artemisia argyi* against *Oryzaephilus surinamensis* (Linnaeus) (Coleoptera: Silvanidae). *African Journal of Microbiology Research* 5, 2816-2819.

Maciel, M.V., Morais, S.M., Bevilaqua, CM.L., Silva, R.A., Barros, R.S., Sousa, R.N., Sousa, S.C., Brito, E.S., and Souza-Neto, M.A., 2010. Chemical composition of eucalyptus spp. essential oil and their insecticidal effects of *Lutzomyia longipalps. Veterinary Parasitology* 167, 1-7.

Magalisl, B., Casanueva, M.E., Arbert, C.C., Agvilera, M.A., Hernandez, V.J., and Becerra, V., 2008. Effects of essential oils from five plant species against the gravary weevils *Sitophilus zeamis* and *Acanthoscelides obtectus* (Coleoptera). *Journal of the Chilean Chemical Society* 53.

Mahfuz, I., and Khalequzzaman, M., 2007. Contact and fumigant toxicity of essential oils against *Callosobruchus maculates. Univ. J. Zool.* 26, 63-66.

Mahmoudvand, M., Abbasipour, H., Hosseinpour, M.H., Rastegar, F., and Basij, M., 2011. Using some plant essential oils as natural fumigants against adults of *Callosobruchus maculates* (F.) (Coleoptera: Bruchidae). *Munis entomology and Zoology* 6, 150-154.

Maini, H.C., Pathak, P.H., and Krishna, S.S., 1993. Effect of certain volatile chemicals and other factor on the reproductive biology of *Corcyra cephalonica*. *Annals of Entomology* 17, 59-65.

Mareggiani, G., Russo, S. and Rocca, M., 2008. *Eucalyptus globules* (Myrtaceae) essential oil: efficacy against *Aphis gossypii* (Hemiptera: Aphiddae), an agricultural pest. Revista *Latinoamericana Química* 36, 16-20.

Masamba, W.R.L., Kamanula, J.F.M., Henry, E.M.T., and Nyirenda, G.K.C., 2003. Extraction and analysis of lemongrass (*Cymbopogon citrates*) oil: an essential oil with potential to control the Larger Grain Borer (*Prostephanus trumcatus*) in stored products in Malawi. *Malawi Journal of Agricultural Sciences* 2, 56-64.

Mishra, B.B., Tripathi, S.P., and Tripathi, C.P.M., 2011. Contact toxicity of essential oil of *Citrus reticulate* fruit peels against stored grain pests *Sitophilus oryzae* (Linnaeus) and *Tribolium castanaeum* (Herbst). *World Journal of Zoology* 6, 301-311.

Mkolo, N.M., Olowoyo, J.O., Sako, K.B., Mdakane, S.T.R., Mitonga, M.M.A., and Magano, S.R., 2011. Repellency and toxicity of essential oils of *Mentha piperita* and *Mentha spicata* on larvae and adult of *Amblyomma hebraeum* (Acari; Ixodidae). *Science Journal of Microbiology.*

Moore, S.J., Hill, N., Ruiz, C., and Cameron, M.M., 2007. Field evaluation of traditionally used plant – based insect repellents and fumigants

against the malaria vector *Anopheles darlingii* in Riberatta, Bolivian Amazon. *Journal of Medical Entomology* 44, 624-630.

Morawej, G., and Abbar, S., 2008. Fumigant toxicity of essential oils against cowpea seed beetle *Callosobruchus maculates. Journal of Biological Science* 11, 48-54.

Moyler, D., 1998. Presented at the International Federation of Essential oils and Aroma Trades - 21st International Conference on Essential Oils and Aroma's, London, 8-12.

Nair, S. and Thomas, J., 2001. Evaluation of the chemosterilant effect of *Acorus calamus* L. extracts on melon fly, *Bactrocera cucurbitae* COQ. *Journal of Tropical Agriculture* 39, 145-148.

Nattudurai, G., Paulraj, M.J., and Ignacimuthu, S., 2010. Fumigant toxicity of volatile synthetic compounds and natural oils against the red flour beetle *Tribolium castanaeum* (Herbst) (Coleoptera: Tenebrionidae). *Journal Of King Saud University- Science* 24, 153-159.

Negahban, M., and Moharramipour, S., 2007. Fumigant toxicity of *Eucalyptus intertexta*, *Eucalyptus sargentii* and *Eucalyptus camaldulensis* against stored- product beetles. *Journal of Applied Entomology* 131, 256-261.

Nerio, L.S., Olivero-Verbel, J., and Stashenko, E.E., 2009. Repellent activity of essential oils from seven aromatic plants grown in Colombia against *Sitophilus zeamais* Motschulsky (Coleoptera). *Journal of Stored Products Research* 45, 212–214.

Ngamo, T.S.L., Ngatanko, I., Ngassou, M.B., Mapongmestesm, P.M., and Hance, T., 2007. Insecticidal efficacy of essential oils of 5 aromatic plants tested both alone and in combination towards *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). *Research Journal Of Agriculture and biological Science* 2, 75-80.

Obeng-Ofori, D., Reichmuth, C.H., Bekele, A.J., and Hassanali, A., 2010. Toxicity and protectant potential of camphor, a major component of essential oil of *Ocimum kilimandscharicum* against four stored product beetles. *International Journal of Pest Management* 44, 203-209.

Obeng-Ofori, Rrichmuth, D., Bekele, C.H., and Hassanali, A.J., 1998. Toxicity and protectant potential of camphor, a major component of essential oil of *Ocimum kilimandscharicum*, against four stored product beetles. *Journal of Pest Management* 44, 203-209.

Oparaeke, A.M. and Dike, M.C., 1996. Comparison of Garlic and Lemon grass products in the control of *Callosobruchus maculates* F. (Coleoptera. Bruchidae on stored cowpea grains. Nig. *Journal of Entomology* 13, 73-80.

Owolabi, M.S., Oladimeji, M.O., Lajide, L., Singh, G., Marimuthu, P., and Isidorov, V.A., 2009. Bioactivity of three plant derived essential oils against the maize weevils *Sitophilus zeamis* (Motschulsky) and cowpea weevils *Callosobruchus maculates* (Fabricius). *Electronic journal of environmental, agricultural and food chemistry* 8, 828-835.

Padilha de Paula, J., Gomes – Carneiro, MR., and Pavmgartten, F.J.R., 2003. Chemical composition, toxicity and mosquito repellency of *Ocimum selloi* oil. *Journal of ethnopharmacology* 88, 253-260.

Panella, N. A., Karchesy, J., Maupin, G.O., Malan, J.C.S., and Piesman, J., 1997. Susceptibility of immature *Ixodes scapularis* (Acari: Ixodidae) to plant-derived acaricides. *Journal Medical Entomology* 34, 340-345.

Paoletti, M.G., and Pimental, D., 2000. Environmental risks of pesticides versus genetic engineering for agricultural pest control. *Journal of Agricultural and Environmental Ethics* 12, 279-303.

Papachristos, D.P., and Stamopoulos, D.C., 2002. Repellent, toxic and reproduction inhibitory effects of essential oils vapours on *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). *Journal of Stored Products Research* 38, 117-128.

Paranagama, P.A., Adhikari, A.A.C.K., Abeywickrama, K.P., and Premarathne Bandra, K.A.N., 2002. Toxicity and repellant activity of *Cymbopogon citrates* (D.C.) Stapf. and *Murraya koenigii* Sprang against *Callosobruchus maculates* (F.) (Coleoptera; Bruchidae). *Tropical Agricultural Research and Extension* 5, 1-2.

Pathak, P.H. and Krishna, S.S., 1985. Neem seed oil, a capable ingredient to check rice moth reproduction (Lepid, Gallaridae). *J. ang. Ent.* 100, 33-35.

Pathak, P.H. and Krishna, S.S., 1991. Postembryonic development and reproduction in *Corcyra cephalonica* (Stainton) (Lepidoptera:

Noctudae) on exposure to eucalyptus and neem oil volatiles. *Journal Of Chemicals Ecology*. 17, 2553 – 2558.

Phillips, T.W., and Throne, J. E., 2010. Throne Biorational Approaches to Managing Stored-Product Insects Annual. *Review of Entomology* 55, 375-97.

Pimentel, D. 1980. Handbook of energy utili-zation in agriculture. Boca Raton (FL): CRC Press.

Popovic, Z., Kostic, M., Popovic, S., and Skoric S., 2006. Bioactivities of essential oils from basil and sage to *Sitophilus oryzae* L *Biotechnology & Biotechnolological Equipment* 1, 36 -40.

Prabhakaran, S., 2006. Commercial performance and global development status of profume gas fumigant. Proceedings of the ninth international working conference on stored product protection 635 – 641.

Prameela, M., 1997. Bioinsecticides in the physiology of red cotton bug *Dysdercus cingulatus* Fabr. (Heteroptera: Pyrrhocoridae). Ph.D. Thesis, University of Kerala.

Priestley, C.M., Williamson, E.M., Wafford, K.A., and Sattelle, D.B., 2003. Thymol, a constituent of thyme essential oil, is a positive allosteric modulator of human GABA receptors and a homo-oligomeric GABA receptors from *Drosophila melanogaster. British Journal Of Pharmacolology* 140, 1363-1372.

Raguraman, S., and Singh, D., 1997. Biopotentials of *Azadirachta indica* and Cedrus deodara oils on *Callosobruchus chinensis. International Journal of Pharmacognory* 35, 344 – 348.

Rahman, M.M., and Schmidt, G.H., 1999. Effect of *Acorus calamus* (L.) (Araceae) essential oil vapours from various origin on *Callosobruchus phaseoli* (Gyiienhal) (Coleoptera: Bruchidae). *Journal of Stored Products Research* 35, 285-295.

Rahuman, A.A., Bagavan, A., Kamaraj, C., Vadivelu, M., Zahir, A.A., Elango, G., and Pandivan, G., 2009. Evaluation of indigenous plant extracts against larvae of *Culex quinquefasciatus* Say (Diptera: Culicidae). *Parasitology Research* 104, 637-643.

Rajendran, S., and Sriranjini, V., 2008. Plant products as fumigants for stored-product insect control. *Journal of Stored Product Research* 44, 126-135.

Rao, I.G., and Singh, D.K., 2001. Combinations of *Azadirachta indica* and *Cedrus deodara* oil with piperonyl butoxide, MGK-264 and Embelia ribes against Lymnaea acuminate. *Chemosphere* 44, 1691-1695.

Regnault-roger, C., and Hamoraoui, A., 1995. Fumigant toxic activity and reproductive inhibition induced by monoterpenes on *Acanthoscelides obtectus* (Say) (Coleoptera), a bruchid of kidney bean (*Phaseolus vulgaris* L.). *Journal of Stored Product Research* 31, 291-299.

Regnault-Roger,C., Philogene, B.J.R., and Vincent C., 2004. Biopesticidas de origen vegetal. Mundi-Prensa. *Madrid.* 337.

Robert, I.K., 2001. Handbook of pesticide toxicology. New York: Academic Press; p. 823.

Rozman, V., Klinovic, I., Liska, A., 2006. Bioactivity of 1,8- cineole, camphor and carvacrol against rusty grain beetle (*Cryptolestes ferrugineus* Steph.) on stored wheat. Proceedings of the 9th international working conference on stored product protection 687-694.

Russel, V.M., Schulter, G.G., and Roorda, F.A., 1980. Laboratory observations on the development of the rice moth, *C. cephalonica* (stainton) (Lepidoptera : Galleriidae) in millet and sorghum at 28°C and different relative humidities. *Zeischrift fur Angewandte Entamologie* 89, 488-98.

Sahaf, B.Z., Moharramipour, S., and Meshkatalsadat, M.H., 2008. Fumigant toxicity of essential oil from *Vitex pseudo-negundo* against *Tribolium castaneum* (Herbst) and *Sitophilus oryzae* (L.). *Journal of Asia-Pacific Entomology* 11, 175–179.

Saxena, B.P., Koul, O., and Tikku, K., 1976. Nontoxic protectants against the stored grain insect pests. *Bull. Grain Technol.* 14, 190-19.

Senguttuvan, T., Kareem, A.A. & Rajendran, R., 1995. Effects of plant products and edible oils against rice moth *Corcyra cephalonica* Stainton in stored groundnuts. *Journal of Stored Products Research* 31, 207-210.

Shaaya, E., Kostjukuvsky, J., Eilberg, C., and Sukprakarn 1997. Plant oils as fumigant and contact Insecticides for the control of stored-product insects. *Journal of Stored Products Research* 33, 7-15.

Shaaya, E., Ravid, E., Paster, N., Juven, B., Zisman, U., and Pissarau, V., 1991. Fumigant toxicity of essential oils against four major stored product insects. *International Journal of Tropical Insect science* 21, 61-66.

Shalaby, A.A., Allam, K.A., Mostafa, A.A., and Fahmy, S.M., 1998. Insecticidal properties of citrus oils against *Culex pipiens* and *Musca domestica. Journal of the Egyptian society of Parasitology* 28, 595-606.

Sharma, N., Dubey, N.K., and Sharma, K., 2011. Screening of insecticidal and antifungal activity of *Origanum majorana* oil against *Callosobruchus chinensis* (L.) and Aspergillus spp. *Research Journal of Agriculture and Biological Sciences* 7, 223-227.

Shinde, U.A., Phadke, A.S., Nair, A.M., Mungantiwar, A.A., Dikshit, V.J. and Saraf, M.N., 1999. Preliminary studies on the anti-inflammatory and analgesic activity of *Cedrus deodara* (Roxb.) Loud. wood oil. *Journal Of Ethnopharmacolology* 65, 21-27.

Shukla, A.C., Shahi, S.K., Dikshit, A., Saksena, V.C., 2001. Plant product as a fumigant for the management of stored product pests. Donahaye, E.J., Navarro, S. and Leesch J.G. [Eds.] (2001) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products,

Fresno, CA. 29 Oct. - 3 Nov. 2000, Executive Printing Services, Clovis, CA, U.S.A. pp. 125-132.

Singh, D., and Agarwal, S.K., 1987. Himachalol and himachalene: insecticidal principles of Himalayan cedarwood oil. *Journal of Chemical Ecology* 14, 1145 – 1151.

Singh, D., Siddiqui, M.S., and Sharma, S., 1989. Reproduction redartdent and fumigant properties in essential oils against rice weevil (Coleoptera: Curculionidae) in stored wheat. *Journal of Economic Entomology* 82, 723- 733.

Singh, P.K., 2010. A decentralized and holistic approach for grain management in India Current Science 99, 1179-1180.

Singh, R., Koul, O., Rup, P.J., and Jindal, J., 2011. Oviposition and feeding behavior of the maize borer, *Chilo partellus*, in response to eight essential oils allelochemicals. *Entomologia Experimentalis et Applicata* 138, 55-64.

Sivakumar, C., Chandrasekaran, S., Vijayaraghavan, C., and Selvara, S., 2010. Fumigant toxicity of essential oils against pulse beetle, (F.) (Coleoptera: Bruchidae). *Journal of Biopesticides* 3, 317-319.

Sreelatha, K.B., and Geetha, P.R., 2010. Disruption of oocyte development and vitellogenesis in *Oryctes rhinoceros* treated with methanolic extract of Eupatorium odoratum leaves. *Journal of Biopesticides* 3, 253-258.

Tah, G.T.T., Seri-Kouassi, B., Aboua, L.R.N., and Koua, K.H., 2011. Insecticidal activity of essential oil of *Eucalyptus platyphylla* and

Mentha piperita on cocoa bean stocks insects. *European Journal of Scientific Research* 49, 177-186.

Tawastin, A., Wratten, S.D., Scott, R.R., Thavara, U., Techandamrongsin, Y., 2001. Repellency of volatile oils from plants against three mosquito vectors. *Journal of vector Ecology* 26, 76-82.

Taylor, R.W.D., 1989. Phosphine – a major fumigant at risk. *International Pest Control* 31, 10-14.

Toloza, A.C., Lucia A., Zerba, E., Masuh, H., and Picollo, M.I., 2008. Interspecific hybridization of eucalyptus as a potential tool to improve the bioactivity of essential oils against permethrin-resistant head lice from Argentina. *Bioresource Technolology* 99, 7341-7347.

Tripathi, A.K., Prajapati, V., Aggarwal, K.K., Khanuj, S.P.S., and Kumar, S., 2000. Repellency and toxicity of oil from *Artemisia annua* to certain stored-product beetles. *Journal of Economic Entomology* 93, 43-47.

Tripathi, A.K., Prajapati, V., Verma, N., Bahl, J.R., Bansal, R.P., Khanuja, S.P.S., and Kumar, S., 2002. Bioactivities of the leaf essential oil of *Curcuma longa* (Var. Ch-66) on three species of stored product beetles (Coleoptera). *Journal of Economical Entomology* 95, 183-189.

Trongtokit, Y., Rongsriyam, Y., Komalamisra, N., and Apiwathnasorn, C., 2005. Comparitive study of 38 essential oils against mosquito bites. *Phytotherapy Research* 19, 303-309.

Tuni, I., and Shinkaya, S., 1998. Sensitivity of two greenhouse pests to vapour essential oils. *Entomologia Experimentalis et Applicata* 86. 183-187.

Walling, L.L., 2000. The myriad plant responses to herbivores. *Journal of Plant Growth Regululation* 19, 195-216.

Yang, P., and Ma, Y., 2005. Repellent effect of plant essential oils against *Aedes albopictus. Journal of Vector Ecology* 30, 231-234.

Zewde, D.K., and Jembere, B., 2010. Evaluation of orange peel *Citrus sinensis* (L) as a source of repellent, toxicant and protectant against *Zabrotes subfasciatus* (Coleoptera: Bruchidae) *Momoma Eucthopian Journal of Science* 2, 61-75.